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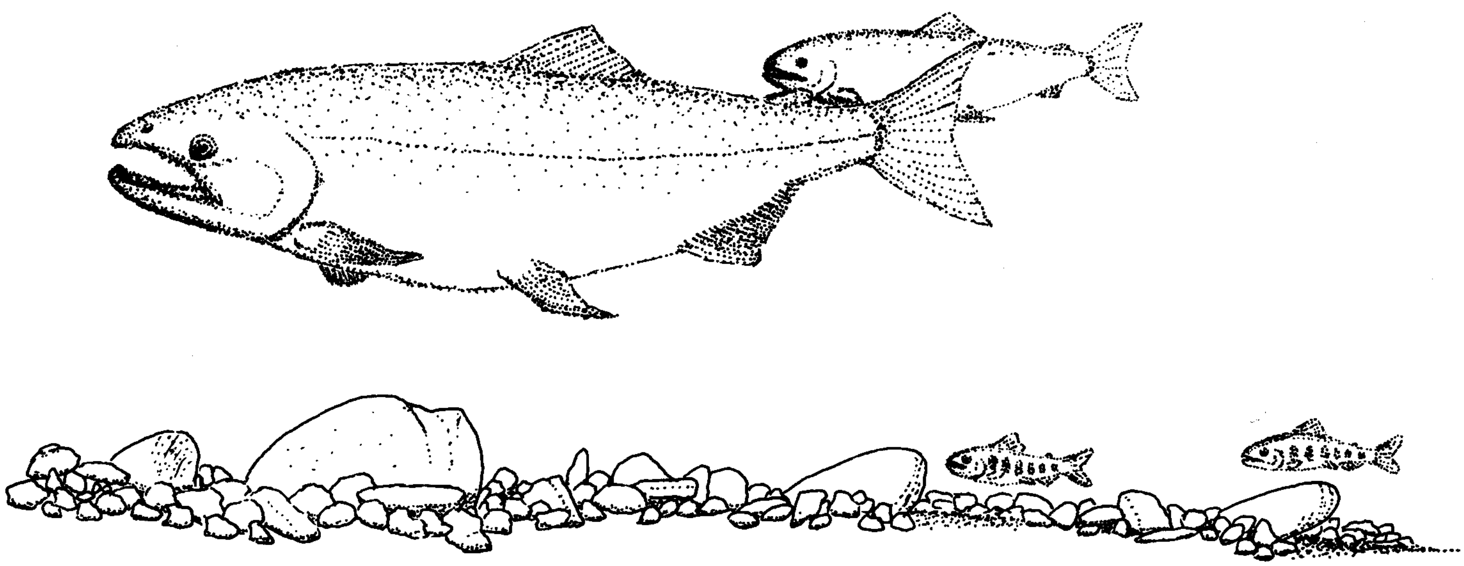

A REVIEW OF AND PROPOSED SOLUTION TO THE PROBLEM OF MIGRANT SALMONID PASSAGE BY THE ELWHA RIVER DAMS

by

P.L. Wampler,[1] R.F. McVein,[2] J.M. Hiss,[1]
and R.C. Wunderlich[1]

[1] U.S. Fish and Wildlife Service
Fisheries Assistance Office
Olympia, WA

and

[2] U.S. Fish and Wildlife Service
Division of Engineering
Portland, OR

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INTRODUCTION

In 1983, managers at Olympic National Park (ONP), located on Washington's Olympic Peninsula (Figure 1), began an effort to fulfill an important ONP mandate. That mandate was to restore to ONP streams the runs of anadromous salmon and trout that flourished there prior to habitat impacts associated with regional development. One of the peninsula's most productive streams, the Elwha River, was permanently blocked by the construction of Elwha Dam in 1910, at river mile (RM) 4.9. Prior to 1910 the Elwha was well known for its production of large salmon and steelhead runs (Washington Department of Fisheries 1971). These included spring and fall chinook, coho, pink, chum, steelhead, and sea-run cutthroat (Mausolf 1977). Elwha fall chinook, in particular, were known to attain unusually large physical size.

Many miles of excellent upstream aquatic habitat were further blocked by construction of a second high dam, Glines Canyon Dam, in 1926 at RM 13.4. These two dams, now owned and operated by the Crown Zellerbach Corporation (CZ), contain no provisions built specifically to pass either upstream or downstream migrating fish. With the exception of one experimental release of steelhead trout fry in 1983, only resident salmonid populations presently exist above the Elwha Dam.

The Elwha River drains into the Strait of Juan de Fuca after flowing northward approximately 45 miles through terrain that varies from steep-sided canyons to relatively narrow, lower gradient valleys. Lake Mills, which forms behind 190-foot high Glines Canyon Dam, is about 2.5 miles long and has limited storage capacity. About 8.5 miles downstream, 100-foot high Elwha Dam forms Lake Aldwell, which is about 3 miles long. From RM 2.5 to the river mouth, terrain surrounding the river becomes quite flat.

Elwha Mitigation

Despite the great loss of anadromous fish production that resulted from damming the Elwha River, the level of mitigation has been low. The original Elwha Dam was in apparent violation of state law because it did not provide a fishway. No serious consideration was given to fish passage facilities in planning the dam. The state chose instead to accept funding for construction of a fish hatchery downstream of the dam. Within eight years that hatchery was abandoned. Mitigation was not actively pursued again until the early 1970's when CZ's "Elwha Project" was under consideration for licensing by the Federal Energy Regulatory Commission (FERC). The offshoot from associated negotiation between CZ and the Washington Department of Fisheries (WDF) was a settlement for partial funding by CZ of a chinook and coho salmon rearing channel (Elwha Rearing Channel) and annual O&M costs (Robert Gerke, WDF, personal communication). Also, CZ agreed that in the future they would operate Elwha Dam as a run-of-the-river plant, to reduce impacts upon downstream anadromous salmonids.

The other species of salmon and anadromous trout impacted by the dams (including spring chinook) have never been mitigated (Robert Gerke, WDF,

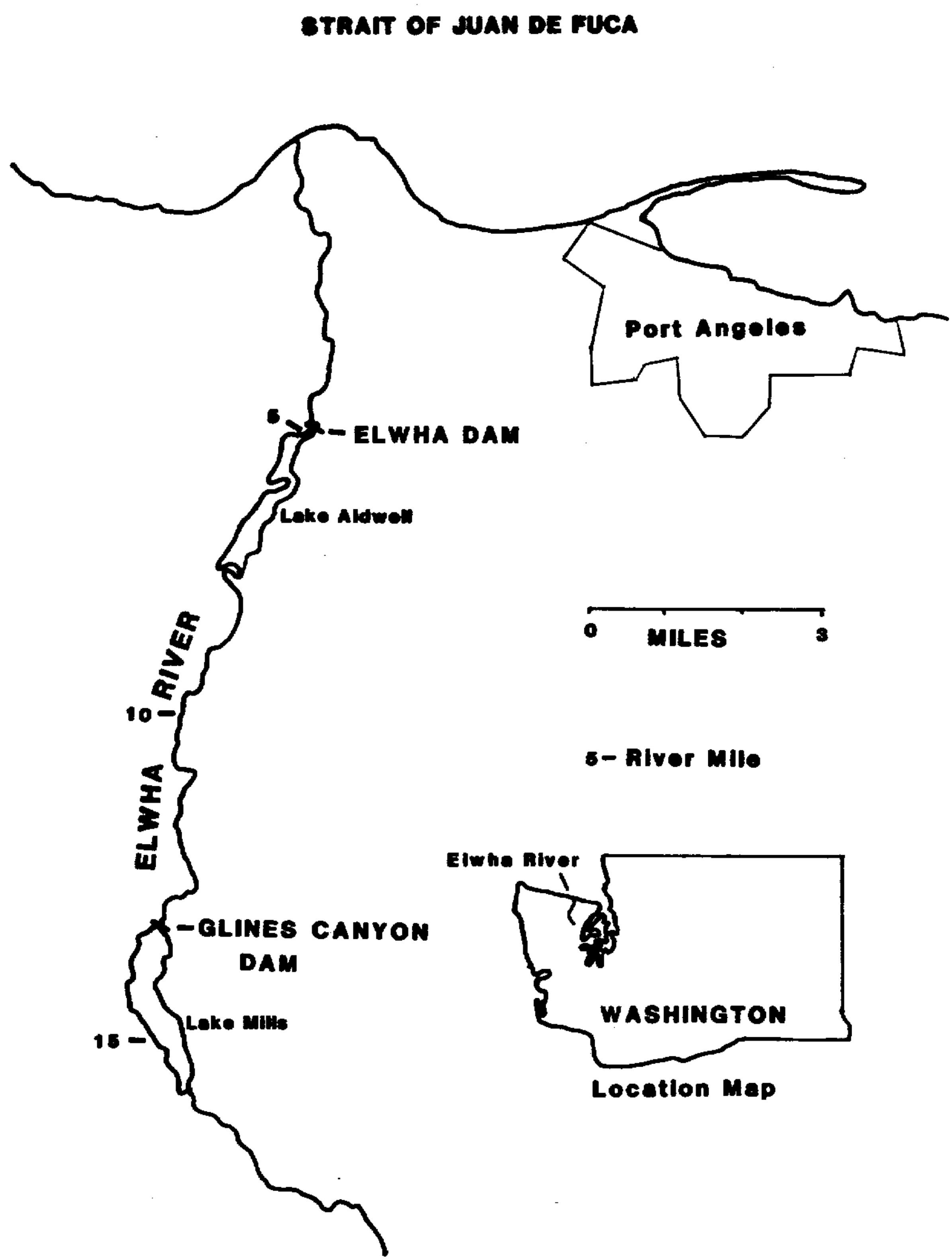

Figure 1. The lower Elwha River.

Gary Fenton, Washington Department of Game (WDG), personal communications). Furthermore, coho salmon are no longer reared at the Elwha Rearing Channel. The WDG has planted winter steelhead smolts in the lower river for many years, and more recently, they have also planted summer steelhead smolts. However, the WDG receives no outside funding to support these programs. In addition, the Lower Elwha tribal hatchery rears and releases fall chinook, coho, chum, and winter steelhead into the lower Elwha.

Previous Elwha Research

Following is a brief chronological review of fisheries studies relating to restoration of Elwha anadromous salmonids.

In 1954, WDF reported results of a study to develop a valid technique for estimating survival of downstream migrants passing the Elwha Dams (Schoeneman and Junge 1954). Their study showed that: chinook fingerlings passed through the Elwha Dam's turbines without mortalities, but only 67% survived the Glines Canyon Dam turbine; chinook fingerlings survived at a higher rate after passing the Glines Canyon Dam spillway (94%) than they did the Elwha Dam spillway (63%); chinook fingerlings will sound 65 feet to the Glines turbine intake for egress if there is insufficient attraction flow at the spillway; 92% of coho yearlings survived after passing over the Glines spillway while 70% survived after passing through the Glines turbine; and coho yearlings are much less likely to sound to the Glines turbine intake for egress, but will remain in the lake until a surface exit appears.

In 1971, WDF assessed the habitat available for salmon above Elwha Dam. They concluded that at least 8,500 spring chinook adults could be accommodated by habitat ranging as far upstream as RM 41. In addition, they estimated that several thousand coho adults could be accommodated. Moreover, they observed that much of the upriver habitat is located in a pristine area where continued protection is assured.

A complimentary WDG report issued by Stendal and Engman (1973) presented similar escapement estimates for anadromous trout above Elwha Dam. They concluded that 5,100 steelhead trout and about 10,000 sea-run cutthroat trout could be accommodated by the habitat.

In 1984, FAO assessed the behavior and fallback rate of adult steelhead released above Glines Canyon Dam (Wampler 1984). Six groups of Skamania stock summer steelhead received surgically-implanted radio transmitters and were then transported by truck or helicopter to points of release above Glines Canyon Dam. Radio tracking of these fish, performed from August, 1983, to January, 1984, provided data that supported the following conclusions: as many as 35% of the tagged steelhead may have fallen back over Glines Canyon Dam; all fish that fell over the dam probably did so during periods of spill; relatively late release during September increased likelihood of fish distribution into the upper Elwha above Lake Mills. A combination of factors prevented gathering data to determine whether any tagged steelhead actually attempted to spawn.

During the same general time period, FAO evaluated survival of juvenile coho passing through Elwha Dam and survival of freely emigrating coho passing through both dams (Wunderlich 1983, 1984). The 1983 feasibility study conservatively estimated that about 63% of freely emigrating coho smolts survived passage through both dams. Results also suggested that coho smolts in Lake Mills did not pass Glines Canyon Dam until spilling began. In 1984, FAO sought to refine the previous year's results and to determine more precisely injury rates and survival rates of coho smolts passing through the Elwha Dam turbines and left spillway. Preliminary results were summarized as follows: mean survival of coho passing freely through both dams was revised to 84%; most fish loss was attributed to the turbines and spillway at Elwha Dam, where tests indicated mortality rates of 11 to 34%, depending on wicket gate and spillgate opening; coho smolts were delayed by Glines Canyon Dam until spilling occurred; and descaling was found to be high among fish passing both dams, apparently due to passing over the tops of the dams during high spring flows.

Purpose of this Study

The purpose of this study was to determine how migrating anadromous salmonids, both adults moving upstream and juveniles moving downstream, can be successfully passed by both dams on the Elwha River. Several areas of investigation were required to satisfy the study purpose. These were:

(1) review of all appropriate literature on fish passage technology;

(2) review of biological factors affecting passage recommendations;

(3) analysis of Elwha River hydrology, dam operations, and patterns of power demand by CZ;

(4) identification of operational and physical plant changes needed to reduce emigrant mortalities and safely pass upstream migrants;

(5) development of alternative passage measures and costs, based on the above information; and

(6) identification of monitoring needs associated with restoration of anadromous runs.

DISCUSSION

The discussion that follows will address, in order, the first three areas of investigation described above.

Review of Fish Passage Literature

I. Passing Adults Upstream

A. Criteria for Success

Fish entering a river and bound for the area upstream of a dam must fulfill the criteria listed by Banks (1969): (1) travel upstream to the area of the fish collection facility; (2) enter the fish collection facility; (3) be transported safely over the dam; (4) avoid falling back over the dam; and (5) find their way through the reservoir to the spawning grounds.

B. Collecting Adults and Passing Them Over Dams

Most upstream fish passage facilities are designed to fulfill criteria (2) and (3) above. We will evaluate various methods on their ability to do so. Fulfillment of other criteria is largely a matter of design and operation of the particular site and facility.

1. Trap and Haul Fish

This method consists of trapping adults at some point downstream of the dam, loading them into a truck, and hauling them upstream of the dam for release. A typical facility consists of: a rack or barrier dam to direct fish into a ladder; an attraction flow to stimulate fish to enter the ladder; a ladder just long enough to accommodate normal high flows and yet encourage fish movement; a trap; a holding area to keep fish until they are periodically removed; a brail to remove fish; and a hopper to load fish into a truck. Most traps also have a specific sorting area where fish can be counted and examined for species composition and for mark recovery.

Trapping and hauling is a proven technique widely applied in the Northwest. It is best suited to high dams (those having more than 100 feet of head) with runs smaller than 20,000 fish per year (Clay 1961). The Wynoochee, Baker, Green Peter, and Mud Mountain Dams are some examples. The Baker facilities have been described in detail by Clay (1961), and the Green Peter facilities were described by Moon (1969). These authors did not note any problems inherent in this mode of fish passage. The method is especially appropriate for spring chinook, because this race has difficulty ascending high ladders (Gunsolus and Eicher 1970).

2. Construct a Complete Ladder Over Dam

This method consists of building a ladder that ascends the entire dam and continues to the forebay pool. Design of adult fish ladders has been described in detail by Clay (1961), Eicher (1973), and Bell (1984). Getting fish to enter a ladder requires the same considerations as for trapping and hauling. Fish passage up the ladder can usually be accomplished with a proper combination of fishway design and operation to insure adequate flows throughout the run. Getting fish to exit the ladder may require adjustable weirs, gates, or submerged orifices at the upper end of the ladder. Ladders have been installed at many locations, and generally have not created problems if they were designed and operated correctly.

3. Transport Fish in a Hopper

This method consists of transporting fish from the dam tailrace to the dam forebay in a hopper suspended from a cable (a tram) or that rides on rails (a trolley). The tram method was proposed for the Elwha dams by Mausolf (1977). Trams or trolleys have all the features of the trapping and hauling method, except that (1) fish are transported in the hopper all the way to their immediate destination, and (2) the method cannot be completly automated (Bell 1984). Installations have been described at Holyoke Dam (Eicher 1970), Beechwood Dam (Clay 1961), the Baker Dams (Wayne 1961), and Foster and Green Peter Dams (Wagner and Ingram 1973). At the latter two dams, a tram has worked successfully, but at Baker the trolley was abandoned because it could not carry enough fish during the run's peak, when up to 3,000 fish per day had to be passed.

4. Construct Fish Locks

The features of fish locks have been described by Clay (1961) and Bell (1984). All locks have an entrance pool to which fish are attracted prior to lock operation. There is usually a crowder to force fish into the lock chamber. Once the fish are in the chamber, the lock closes and fills with water. The fish follow the rising water level, usually to the forebay. In some facilities there is a brail near the forebay to insure that fish leave the lock.

This method is widely used in Scotland, Ireland, and other parts of Europe. In the Northwest only the Bonneville and McNary Dams have locks, and these are almost never used because fish ladders there proved satisfactory. The McNary lock was evaluated for fish passage efficiency but results were inconclusive (Eicher, personal communication). The literature suggests that locks offer no advantages over ladders in terms of fish passage efficiency. They also probably have less fish capacity than ladders per volume of water. At high dams they are probably not as economical as trapping and hauling. Their major advantage, however, is that locks are the only adult passage system that does not appear to injure kelts.

II. Passing Juveniles and Kelts Downstream

Downstream passage should include both juvenile salmonids and steelhead kelts. However, emphasis in this review will be given to juveniles because literature on kelts is very scarce.

A. Effects of Dams and Reservoirs on Migration

Fish leaving spawning and rearing areas upstream of dams face a number of obstacles in their seaward migration: (1) mortality or residualism in the reservoir; (2) mortality in turbines or connected structures; (3) mortality in spillways; (4) mortality in the tailrace; and (5) stranding downstream of the reservoir due to fluctuating water levels. Stendal and Engman (1973) cited these conditions as evidence that downstream fish passage is impossible on the Elwha. However, our review of the literature both before and since that time calls into question that point of view.

1. Mortality or Residualism in the Reservoir

Fish may suffer mortality before arriving at the forebay, or after they have become concentrated there. Mortality enroute to the forebay would be likely if the current in the reservoir were so slow that fish became disoriented. They would then be more exposed to predators that reside in the reservoir than if their migration were uninterrupted. If smolts do not exit the reservoir within their normal season of migration, they may revert to parr and reside in the reservoir for a year or more, or never migrate at all.

In recent tests, orientation appeared to be no problem for yearling coho migrating through Lake Aldwell (Wunderlich 1983). No problem is foreseen for salmonids in either Elwha reservoir (Schoeneman and Junge 1954; WDF 1971; Katz et al. 1975; Pearce letter 1981) because Lake Aldwell is controlled as run-of-the-river and Lake Mills has only limited storage capacity. In other reservoirs with similar conditions downstream migrants did not experience disorientation (Gunsolus and Eicher 1970; Ruggles and Murray 1983).

Inadequate forebay passage facilities or spill procedure can lead to juvenile delays or even residualism. Delay of coho and steelhead outmigrants was significant at the Wynoochee Reservoir (Dunn 1978). Residualism was also a problem for summer steelhead smolts at Foster Dam (Oregon Wildlife Commission 1975).

Entrapment has occurred in Lake Mills during periods of non-spill. Schoeneman and Junge (1954) reported that coho yearlings lingered in the forebay of Lake Mills and would not sound to the turbine intake during non-spill periods. Wunderlich (1983, 1984) also found that coho emigration was delayed up to several weeks by lack of spill at Glines Canyon Dam, despite continuous withdrawal at the turbine intake during the period of delay. Prolonged entrapment could result in increased vulnerability to predation, or, if enough time elapsed, to residualism (Ruggles and Murray 1983). However, in Lake Mills there has been no evidence of serious predation for yearling coho holding two to three weeks, based on recent studies (Wunderlich 1983, 1984).

2. Mortality in Turbines

a. Glines Canyon Dam

Mortality of fish that pass through the turbine appears to be a significant problem at this dam. Schoeneman and Junge (1954) found 30% mortality for yearling coho and 33% for fingerling chinook. They believed there was a greater problem for chinook because this species tended to sound to the turbine intake, which is located 65 feet below the normal pool elevation.

Chinook appeared to sound only if an exit via spill was not available. In contrast, coho yearlings tended to mill in the reservoir and wait until spill occurred before passing downstream. This behavior was apparently confirmed by Wunderlich (1983). Studies on the Columbia River suggested that chinook were especially apt to enter turbines. There, chinook migrated through turbines before spring runoff, when there was less opportunity to leave reservoirs through spillways than later in the season. Coho migration, in contrast, was timed with higher flows (Raymond 1979), so they were more apt to leave via the spillways. This difference in behavior between the two species may not always occur. For instance, Gunsolus and Eicher (1970) found both coho and chinook sounding to 120 feet in the North Fork Clackamas when surface spill was not available. In the White River, nearly 100% of both coho and chinook emigrants sounded over 100 feet to pass through Mud Mountain Dam (Regenthal and Rees 1957).

Turbine entry may be more of a problem in the summer than in the spring for all species. Investigators of BioSonics (1984) reported deeper distribution of chinook and steelhead in the forebay of a Columbia River dam as the season progressed, implying a greater tendency of both species to enter turbines in early summer than in spring.

b. Elwha Dam

Schoeneman and Junge (1954) reported no mortality for chinook fingerlings in Elwha turbines. However, Wunderlich (1984) found mortalities of 12 to 30% for coho yearlings. These latest results are consistent with the general observation that larger fish are more susceptible to turbine damage than smaller ones (Ruggles et al. 1981). For example, differential mortality due to size was observed in Atlantic salmon ranging in length from 130 to 190 centimeters (Ruggles and Collins 1981) and in brook trout ranging from 90 to 140 cm fork length (Collins and Ruggles 1982). On the Elwha, naturally migrating steelhead smolts are likely to be larger and thus subject to possibly greater mortality than observed for coho.

Wicket gate opening has been shown to influence turbine mortality. Specifically, wicket gate openings well away from the optimum for efficient power generation tend to cause more mortality than openings set for maximum efficiency. Most turbines appear to be designed to operate at maximum efficiency with a wicket gate opening of about 75%. Tests at different installations have shown increased mortality for gate openings of 50% and 100% (Ruggles and Collins 1981). Since optimum wicket gate openings have not been determined at the Elwha Dam, and since tests in the 1954 studies did not control the wicket gate opening, there is some doubt as to whether observed mortalities represent the best case, the worst case, or some intermediate level.

Tailrace elevation becomes an important factor in turbine mortality at non-optimum wicket gate openings. It is difficult to say how much influence tailrace elevation has on fish mortality at Elwha Dam because efficiency data are lacking.

Turbulence in the draft tubes can also be a factor in mortality (Bell 1974). Tests of turbine mortality, to date, have not investigated this possibility or isolated it as a problem.

3. Mortality in Spillways

a. Glines Canyon Dam

Survival has been relatively satisfactory in spillway tests. Schoeneman and Junge (1954) observed 8% mortality of coho yearlings. They tested the spillway at gate openings of up to 8 feet, but the gates could open up to 15 feet. What effect this would have on survival is uncertain, but we are not aware of any evidence which suggests mortality would necessarily be any greater. Wunderlich (1983, 1984) also tested yearling coho there and could not necessarily attribute mortality to the spillway. Ruggles and Murray (1983) stated that spillway free fall should not be a source of mortality for individuals under 18 cm in length. Their conclusion was based on tests in which fish were dropped through the air from various heights. Trout 25 to 28 centimeters in length experienced 18% mortality when dropped from heights comparable to the 180 feet of Glines Canyon spillway (Bell and deLacy 1972). This suggests danger mainly for larger steelhead smolts and for all steelhead kelts. On the other hand, at least some survival of larger fish can be expected. This is based on the preliminary observation of a small number of radio-tagged adult steelhead released in Lake Mills that passed safely downstream over one or both dams (Wampler 1984).

Bell and deLacy (1972) point out that free fall experiments may give an optimistic prediction of survival because fish entrained within the water column could be subject to greater forces of deceleration than those falling freely through the air.

An additional source of mortality and injury at Glines Canyon Dam is spilling over the dam crest instead of, or in conjunction with, the spillway itself. This practice results in slightly greater storage and turbine head, but it allows some migrants to pass down the face of the dam and fall against rock at the abutments and base of the dam. Preliminary observations suggest that the high rate of abrasion of coho recovered downstream in 1984 from releases in Lake Mills reflects, at least in part, overtopping at Glines Canyon Dam (Wunderlich 1984).

b. Elwha Dam

The Elwha Dam has spillways on both the right and left banks of the river. The left bank spillway is the only one used during routine operation. Only this spillway has been studied in relation to downstream fish passage.

Mortality in the left bank spillway was reported to be 37% for chinook fingerlings (Schoeneman and Junge 1954) and 11 to 34% for coho yearlings (Wunderlich 1984). Spillways of this type, which dissipate large amounts of energy very suddenly, have been judged detrimental to survival by Gunsolus and Eicher (1970), and Bell and deLacy (1972). A smooth, steady course down the chute is ideal. U.S. Army Corps of Engineers' (1979) tests of chute-type spillways showed that a smoothness equivalent to that of sandpaper was required to avoid abrasion of smolt-sized fish. However, these experiments were performed in only two inches of flow in a model, and the higher flows usually experienced during spill at Elwha Dam may not require such exacting conditions.

The right bank spillway is much rougher and more irregular in shape than the left bank spillway. For this reason it is considered more dangerous to fish.

During higher flows, water may be passed over the Elwha spillgates (both banks) in addition to flow through open spillgates and turbines. Although the volume of water passed in this manner is relatively small, some loss or injury undoubtedly would occur to those migrants passing over the gates and falling into the left or right bank spillways.

4. Mortality in tailraces

Mortality in tailraces of the Elwha dams has been assumed insignificant in past and current investigation on the Elwha, but the literature on other sites is full of instances of tailrace mortality. Therefore, mention is made here of factors which may be present, even if their likelihood is very small. Larson (1978 letter) raised the issue of nitrogen entrainment and subsequent supersaturation. This may happen only at high rates of spill, as observed by Wagner and Ingram (1973) at Green Peter Dam. However, literature reviewed by Ruggles and Murray (1983) suggests that supersaturation is not likely to be created by spillways of the shape present at the Elwha dams. Further, the deep stilling basins and lack of turbulence downstream normally associated with supersaturation (Garton and Nebeker 1977), are not present at the Elwha dams.

Another issue raised by Larson (1978 letter) is the possibility of temperature change between the reservoir and the tailrace at Glines. This problem could occur at Glines Canyon only, where turbine water may be cooler than that which leaves the spillway. Rapid temperature change experienced by fish as they pass from the surface of a reservoir via spillway to a tailrace dominated by cooler turbine water has caused mortality (Ruggles et al. 1981; Ruggles and Murray 1983). This was especially dangerous when surface temperatures at some sites exceeded 50°F (Bell 1984). The probability of similar conditions occurring on the Elwha has not been investigated.

Another potential problem for fish leaving Glines Canyon Dam is sudden decompression that might occur to fish leaving the turbine area. This would occur if they had completely acclimated to pressure at the depth of the turbine entrance. This problem has been noted at some other sites (Bell 1981, 1984).

Finally, tailrace mortality has often occurred when currents from the spillway or draft tubes produced a whirlpool or a backroll (Ruggles and Murray 1983). These conditions have not been observed at either of the Elwha Dams, although systematic observations at all ranges of flow have not been made.

5. Stranding Downstream of Dams

Stranding has been observed downstream of Elwha Dam on several occasions (Larson letter 1978; Engman letter 1982). In the past it apparently occurred on a regular basis as power plant operations "peaked" each day. In recent years it appears that stranding of juvenile fish occurred only during those emergencies that necessitated dropping the turbine load instantaneously.

B. Promoting Safe Passage Downstream Past Reservoirs and Dams

Possible solutions to mortality of downstream migrants caused by turbines have been outlined by Loar (1982). Solutions to spillway mortality have been reviewed by Ruggles et al. (1981).

1. Trap and Haul at Heads of Reservoirs

This method potentially avoids all sources of mortality except stranding. It involves scoop trapping or some other means of collecting a majority of juveniles at the head of each reservoir. Fish are held and transferred to trucks, brought downstream, and released below the dam. Trucking is done for long distances on the Columbia River (Ebel 1980). The question has been raised as to the effect of transportation on the homing abilities of fish. Tests indicated there was little loss of homing tendency in chinook salmon but some loss in steelhead (Slatick et al. 1983). It is doubtful that this would be a major problem for a short transportation distance.

Another problem with transportation has been the high rate of stress on spring chinook (Park et al. 1982, 1983). Stress in handling has not been a problem with other species. Stress to chinook occurred mainly in the tank truck, especially when spring chinook were combined with other species. As a result, trapping and hauling did not significantly improve adult returns of this run.

2. Predator Control in Reservoirs

This method decreases downstream migrant mortality caused by predators residing in the reservoir. Predator control has been practiced in certain reservoirs with large predator populations when there was evidence of damage to the salmon and steelhead runs, such as at Green Peter (Wagner and Ingram 1973). Methods can include drawdown, shocking, netting, or poisoning (Moon 1969; Bell 1984). Success of these measures is usually temporary. If poisoning is chosen, the impact on downstream fish populations must be considered.

3. Spilling During Fish Migration

This method is used to reduce mortality due to fish passing through the turbines. It entails spilling enough volume of water to draw the fish in the forebay to the spillway and away from turbine intakes. Of course, the spillway itself must be safe for fish. Spilling for fish passage may require shutting down the turbines. At some dams, spilling for fish passage can be limited to certain times of day when most fish are migrating. Daily periodicity in migration is most likely when turbidity is low (Bell 1984). At dams with more than one turbine, shutting down the turbines one after another, beginning with the one farthest from the spillway, may help to guide fish to the spillway (Sims 1979). At dams with surface spillways and submerged turbine intakes, spilling for fish passage is most necessary at times of day when fish are inclined to sound and enter turbine intakes (Sims 1979; Johnson et al. 1984; Raemhild 1984a; Orrell, WDF personal communication). However, daily periodicity of fish distribution does not occur at all dams.

Sufficient spill during the spring outmigration appears to be necessary in maintaining adult returns to the Baker Dams (Orrell, WDF, personal communication). Periodic spill during spring to aid fish passage has been practiced at some Columbia River dams (Raemhild 1984a; Ruggles et al. 1981). The procedure has generally resulted in increased survival but such operations have been considerably more successful at some sites than at others (Raymond 1979). For instance, it has been difficult to pass more than 60% of the fish through the spillway for any amount of spill at Rocky Reach Dam (Raemhild 1984b). The effectiveness of such a program may also depend greatly on the discharge for the particular water year (Johnson et al. 1984).

4. Changes Related to Turbines

Certain measures at some power houses reduced mortality or injury to fish that passed through the penstocks, turbines, and draft tubes.

a. Adjust Turbines for Optimum Fish Passage

Operating turbines at their greatest electrical efficiency reduces cavitation and the corresponding danger to fish (Bell 1981, 1984). Cavitation is defined as the rapid formation and collapse of vapor pockets in regions of very low water pressure. These might occur at the downstream side of the turbine or in the draft tube. Efficiency of a turbine can be changed by adjusting the wicket gate opening (Ruggles et al. 1981). In Francis turbines, the best efficiency is usually obtained only from a narrow range of openings. However, even the most efficient operation of turbines cannot always reduce fish mortality to acceptable levels because mechanical damage to fish in the runner can occur, in the absence of cavitation. For example, at the Cushman plant, during the most efficient turbine operation, mortality remained at about 23% (Bell 1981).

b. Smooth the Penstock and Draft Tube

Elimination of rough edges inside penstocks and tailraces at the Sullivan powerhouse reduced mortalities there (Eicher 1981).

c. Raise the Tailrace Level

When the level of the tailrace is too far below the centerline of the turbine, cavitation and consequent fish mortality is more likely than when the tailrace level is higher (Eicher 1970; Ruggles et al. 1981; Bell 1984). The problem is most likely when the turbine is not operated at highest efficiency (Collins and Ruggles 1982).

One way to raise the tailrace is to insure that the total flow through turbine and spillway are at the highest possible level during fish migration (Bell 1981). Another way is to install a weir below the dam (Wayne 1961). The weir built below Baker Dam also serves to guide adult upstream migrants to the trap.

d. Modify the Turbine

Several changes in turbines may reduce mortality. Perhaps the simplest is to install an air vent to reduce cavitation. Ruggles et al. (1981) believed this would reduce the effect of tailrace elevation on mortality. However, air venting in the draft tube has not resulted in improved survival at every installation (Collins and Ruggles 1981). Another alternative, suggested by Ruggles and Collins (1981), is to redesign the turbine runners for greater clearance between the blades and the wicket gates. They thought that this should reduce damage to fish, but apparently no tests have been performed.

A third possibility (Webb, WDF personal communication), is to replace the existing turbines with Kaplan runners, at least at Elwha Dam where it would be difficult to prevent fish from entering turbine penstocks. Kaplan runners achieve higher efficiency over a wider range of wicket gate openings than is possible for Francis turbines. However, no such replacements have been reported to date, at Elwha or elsewhere.

5. Divert Fish from Both Spill and Turbines

Many ways exist to eliminate mortality in the turbines, the spillway, and the tailrace by capturing fish in the forebay or penstock and diverting them to a safe point downstream. The number of fish diversion schemes is large. We have selected only those which have some probability, however small, of application at one or both Elwha dams. The literature has been summarized by Kiell (1984), and it was doubtful that any tested technique, in its general form, escaped mention.

a. Gulpers

The general plan of a gulper has been described by Eicher (1970). It consists of a floating inclined plane trap, with pumped attraction flow into the trap. Fish captured by the inclined plane are strained from the attraction water by a horizontal screen, and passed to the tailrace or another point downstream by a much smaller amount of diversion water. Installations have been tested at the Baker, Merwin, Mayfield, and Lookout Point Reservoirs. The Baker gulper has had some difficulty in attracting smolts, apparently because the fish tend to occupy levels of the reservoir so deep that the gulper cannot attract them (Orrell, WDF, personal communication). The installation of net leads increased its effectiveness (Semple 1975), but performance was still not entirely satisfactory. The Merwin gulper has been made to perform satisfactorily with the addition of net leads, and was tested at 74% collection efficiency for yearling coho (Allen and Rothfus 1976). In contrast, the Mayfield gulper was not satisfactory, even with net leads (Webb, WDF, personal communication), and the Lookout Point trap was also ineffective. Most other cases have not yielded consistently good results (Eicher 1970, Pearce letter 1981). The general problem with gulpers is that they lose effectiveness when some other source of attraction flow competes with the gulper's attraction (Hays, Chelan Co. PUD, personal communication).

b. Skimmers

Skimmers are like gulpers except that they are supported by the dam itself; they do not float. They have been described by Eicher (1970) and Bell (1984). Skimmers can either be in a fixed position or be adjustable, riding on rails to follow the forebay level. They have been installed at the Pelton, Green Peter, Cougar, Fall Creek, and Round Butte Dams. The Green Peter installation has had 75 to 84% passage efficiency for chinook, 67% for summer steelhead, but only 33 to 57% for winter steelhead (Wagner and Ingram 1973). On the other hand, the Cougar and Fall Creek facilities have not had consistently good collection efficiency (Moon 1969).

c. Lake Traps

Lake traps have been used successfully to trap smolts at Lake Merwin and Wynoochee Reservoirs (Hamilton et al. 1970; Dunn 1978), but they were not as useful in the White River drainage (Seiler, WDF, personal communication). Lake traps operate on the principle of a fyke trap by guiding fish with net leads to a floating pot and spiller connected by tapered web tunnels. Collection efficiency at Wynoochee ranged from 12 to 56% for hatchery coho, and 7 to 21% for hatchery steelhead (Dunn 1978). Factors affecting efficiency include siting, length and position of leads, and surface water temperature (Fenton, WDG, personal communication).

d. Flumes

These are outlets in the dam which are used specifically for fish passage. Unlike gulpers and skimmers, flumes depend on water flow due to gravity alone to attract fish. Flumes may be only at the surface or at various levels on the face of a dam to accommodate different forebay levels and fish distribution patterns. They have been built at Fall Creek, Wynoochee, Malay Falls, and Alder Dams. Passage was poor at Fall Creek (Bell 1984). At Wynoochee serious problems of residualism -- an estimated 26 to 63% of the coho and 10 to 93% of the steelhead -- developed as fish refused to use the six multi-level outlet tubes provided for passage from the reservoir (Dunn 1978). An unused turbine bay at the Malay Falls Dam attracted only 52% of the Atlantic salmon tested (Ruggles and Murray 1983). However, a surface flume at the Alder Dam passed 97% of the fish tested (Bell and deLacy 1972).

Existing ice or trash flumes have also been utilized for fish passage with varying degrees of success on the Columbia River. Their effectiveness is largely site-specific (Nichols 1979; Johnson et al. 1984; Hays, Chelan Co. PUD personal communication). They are mentioned here because the Glines Canyon Dam was designed with a log sluice, although it is not used.

e. Net Leads

The effectiveness of gulpers, skimmers, lake traps or flumes can sometimes be increased by the addition of net leads (Semple 1975), but effectiveness is site-specific (Ruggles and Collins 1981). Addition of net leads to the Baker collectors increased effectiveness but had no such result at Brownlee Dam. There, trash made it impossible to keep the leads in one piece.

Pearce (1981 letter) considered trash enough of a problem on the Elwha to recommend their elimination from consideration.

f. North Fork Clackamas Design

This dam has a unique and very complex design that combines a skimmer with partial screening of the spillway and use of an adult ladder for attraction and transportation of downstream migrants (Eicher 1958). Downstream passage facilities consist of a flume parallel to the adult ladder with orifices to the ladder. Up to 200 cubic feet per second (cfs) of pumped flow is provided to attract downstream migrants to the collection facility. Any fish remaining in the flume after passing by the orifices are separated from this flow by an angled traveling screen. This screen can also handle the first 500 cfs of spillway flow without impingement. The system has passed about 90% of the coho and steelhead tested, and 70% of the chinook (Gunsolus and Eicher 1970).

g. Partial Screens

Partial screens are used where fish must be diverted from a turbine intake, but where volume of flow or size of the intake prevent screening the total flow. Partial screens are based on the principle that fish in a horizontal penstock tend to rise to the top as flow is constricted. Consequently, such screens are positioned just ahead of some sort of riser to draw fish out of the penstock. In all installations to date, the gatewell of the turbine intake served this function. The screen can be made of either fixed bars, as described by Krcma et al. (1979a, 1980) or traveling, as described by Long et al. (1979). Krcma et al. (1979b, 1982) preferred traveling screens, because of their ease in cleaning.

Fish were either removed from the riser by a dipnet, or allowed to exit through a lighted submerged orifice. Air bubbles have been considered to guide fish upward to the orifice (Long et al. 1979), but have not been tested. Most of the literature indicating the orifice is most practical because it fishes continually. From the orifice fish are sluiced to the tailrace. Orifices were tested for their ability to collect fish from the gatewell. They were usually efficient, but there were exceptions (Sims and Johnson 1979).

Most dams on the Columbia now have partial screens. A majority of these work well, but it depends on the velocity at the particular site. Five to six feet per second are required in the penstock, and the velocity across the screen must be two to four feet per second (Pearce letter 1981). Traveling screens gave up to 87% fish passage efficiency (Long et al. 1979). In most cases the method was efficient with all but subyearling chinook, which tend to swim too deep to be captured efficiently (Krcma et al. 1983). On the other hand, recent tests at Rocky Reach Dam indicated poor passage of steelhead as well as subyearling chinook but good passage of yearling chinook and coho (Hays 1984).

h. Eicher Screens

The Eicher screen (Eicher 1981, 1982), unlike the partial screen, covers the entire cross-section of the penstock and diverts fish into a bypass pipe. As with gulpers and skimmers, most of the bypass flow is screened out and returned to the penstock, while a small transport flow takes fish to the tailrace. Eicher screens are also called pressure screens because they operate at relatively high pressures as opposed to, for example, irrigation screens. Eicher screens depend on high water velocity to passively wash fish by the screen without impingement, while lower pressure screens rely on the fish's ability to swim away from the screen (Miller 1984). Eicher screens require a minimum velocity of about 6 feet per second in the penstock (Eicher, personal communication). Only one Eicher screen is in operation at this time. It was installed at the Sullivan Plant on the Willamette River, and has been evaluated. It passed 99% of the coho, 96% of the spring and fall chinook, and 80% of the steelhead tested, without impingement (Cramer 1983). Laboratory model tests (Wert 1984) showed excellent survival for steelhead smolts and chinook fry and smolts.

i. Locks for Passing Juveniles

Eicher (1964; and personal communication) designed a lock for transporting downstream migrants from a skimmer in the forebay of Round Butte Dam to the tailrace, 365 feet below. A lock was chosen for this purpose to avoid the high velocities that would have been present in a flume. The combined skimmer and lock effectively passed fish from the forebay to the tailrace.

j. Louvers

Louvers are the only behavioral barrier known to be effective in guiding juvenile salmonids away from hazards (Kiell 1984). They are called a behavioral barrier because openings in the louvers are wide enough for fish to pass through, but salmonids are reluctant to make the rapid changes in direction required to do so. Louver installations feature a power channel through which all water passes to the turbines. This usually takes the form of a canal from the dam to the powerhouse. In the canal are mounted several banks of louvers, each bank at an angle to the flow, forming a zigzag pattern across the canal. At the downstream end of each bank is a gap through which fish may pass into a diversion channel, which leads to the tailrace. Louver installations have been described by Ducharme (1972) for a hydroelectric dam in Nova Scotia and by Odenweller and Brown (1982) for a water diversion canal in California. The latter project was particularly successful in passing juvenile salmonids. Louvers require constant flow of about 3 to 5 feet per second. They are easily fouled by trash.

Biological Factors Affecting Passage Recommendations

Successful passage of upstream and downstream migrant fish will require that spill and power generation be carefully regulated to protect fish. Knowledge of migration timing will be essential to such regulation. Review of seasonal migrations, by species and lifestage, will assist fishery managers and dam operators in achieving fish passage goals.

Expected timing of adult entry into the Elwha is best estimated from either run timing of remnant Elwha stocks or timing of respective runs in nearby river systems. Figure 2 shows adult entry timing, based on several sources (Williams et al. 1975; Ken Gilliam, Elwha tribal hatchery, personal communication; Jim Nielson, WDG, personal communication; Jim Deshazo, WDG, personal communication; WDG 1978; WDG 1979).

Expected timing of downstream fry/smolt migrations (Figure 2) is based on remnant run emigration timing and emigration timing in other river systems (William et al. 1975; Wunderlich, FAO, personal communication; Reimers 1971; Bill Wood, WDF, personal communication; WDG 1978; WDG 1979; Royal 1973).

The fry/smolt emigration timing of chinook, coho, and steelhead in Figure 2 was also based on analysis of data collected in 1984 by FAO in the Elwha River (Wunderlich, FAO, personal communication). The FAO trapping studies on the lower Elwha produced data on fish length, date of capture, and diel movement. Emigration date and time information may be used to guide duration of specific dam operations to protect fish. Similarly, fish length in relation to timing may further guide dam operations to protect fish. As described previously, larger fish suffer increased rates of turbine injury. Table 1 presents the results from analysis of emigrant fork length (FL) by species and by month. Table 2 shows a summary of day vs. night movement at the trap for chinook, coho, and steelhead, indicating a preponderance of nighttime movement for these species. Further discussion of the FAO trapping data analysis and related information, as well as discussion of other species/races that may eventually be restored, are presented in Appendix A.

Plant Operations

The power plant at Elwha Dam is used as a primary source of power for production machinery at the CZ pulp and paper mill in Port Angeles. This power is supplemented by the plant at Glines Canyon Dam, from the local public utility district, and from the Bonneville Power Administration. The mill is operated on a 24-hour basis, with resultant power demands. At Elwha Dam, at least two generators are on line at all times (CZ dam operation staff, personal communication).

Glines Canyon Dam powerhouse is usually shut down for about one month, during August or September. During this period stream flow is not high enough for power generation by the single, large turbine (CZ operational records). Stream flow in excess of the system power requirements is passed through the spillway gates.

River Hydrology

The Elwha River is a steep gradient stream draining an area of approximately 310 square miles (see Appendix B, Exhibit 1). The United States Geological Survey (USGS) established gaging station "12045500 Elwha River at McDonald Bridge, near Port Angeles, WA", in October, 1897.

Figure 2. Expected timing of upstream and downstream migrations of restored anadromous runs in the upper Elwha River.

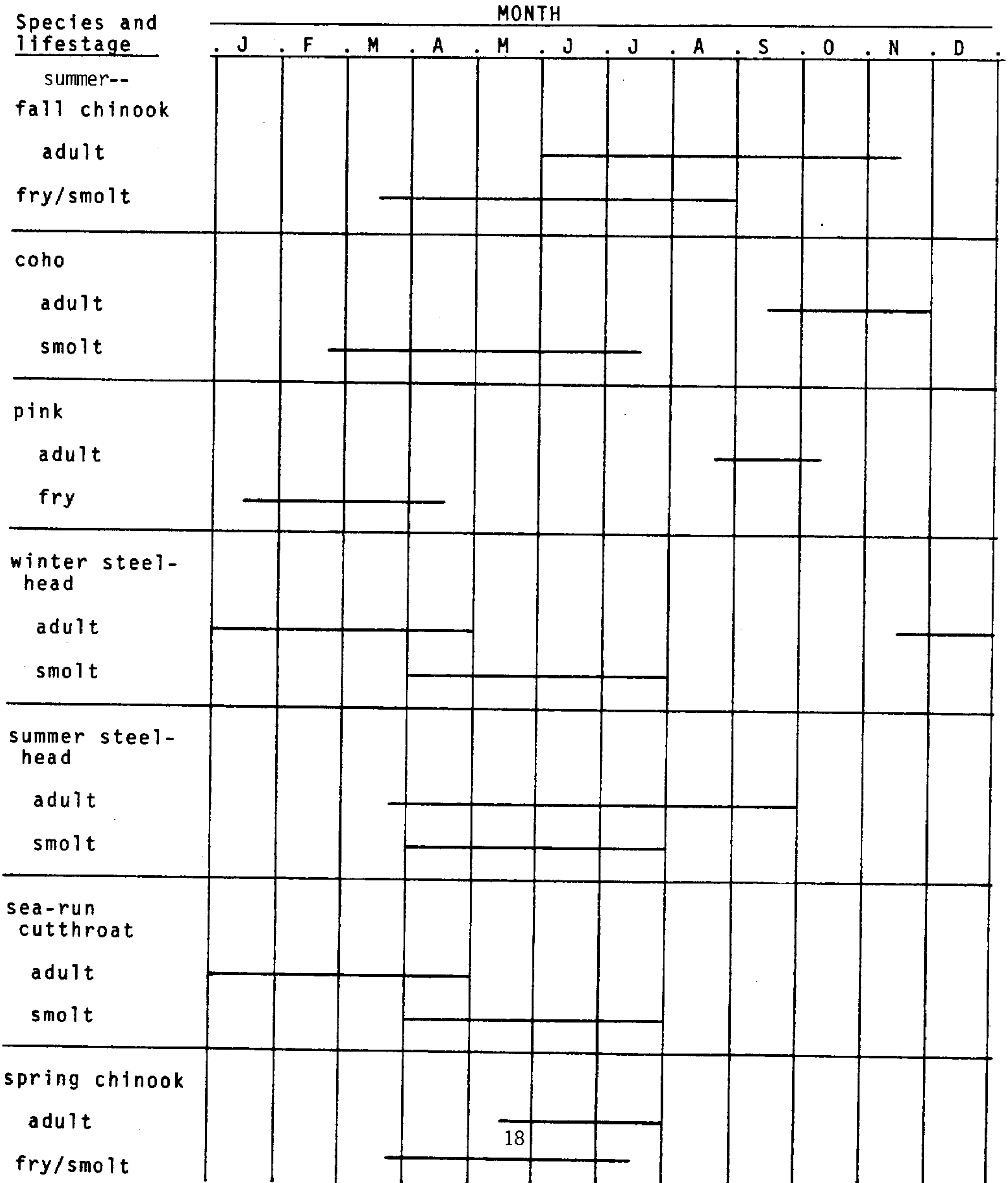

Table 1 . Statistics from analysis of data from downstream migrant trapping performed in the Elwha River by FAO, from late April to early July, 1984.

SPECIES	MONTH	SAMPLE SIZE	FORK LENGTH (mm) RANGE	MEAN	SAMPLE STANDARD DEVIATION	MODE
summer--fall chinook	April	325	36-178	42.3	7.8	42
	May	385	38-181	84.3	34.0	41[a] 120[b]
	June	385	37-165	89.0	20.9	80[a] 128[b]
	July	114	58-108	83.7	9.3	84
coho	April	6	80-130	110.5	17.8	c
	May	290	42-177	133.9	22.5	135
	June	640	46-180	143.5	16.8	150
	July	9	55-162	130.9	40.6	55
steelhead	April	36	158-290	192.4	23.9	195
	May	981	123-272	187.1	54.5	190
	June	152	100-245	188.6	27.5	210
	July	8	159-290	216.2	51.2	c

a: primary mode

b: secondary mode

c: no modal value

Table 2. Day vs. night capture of chinook, coho, and steelhead in the downstream migrant trap operated by FAO in the Elwha River, from late April to early July, 1984.

Species	Time Period	Percent Capture Daylight	Percent Capture Darkness
summer--fall chinook	Late April	1	99
	May	8	92
	June	33	67
	Early July	54	46
coho	Late April	14	86
	May	24	76
	June	21	79
	Early July	33	67
steelhead	Late April	21	79
	May	9	91
	June	24	76
	Early July	12	88

Records are available from October, 1897 to December, 1901, and from October, 1918 to present. This station is located at RM 8.6, 3.7 miles upstream of Elwha Dam and 4.8 miles downstream of Glines Canyon Dam. Exhibit 2 (Appendix B) is a tabulation of the mean monthly flows at the USGS gage for the 10-year period 1971-1980. Maximum and minimum flows for the period of record were 41,600 cfs (Nov. 18, 1897) and 10 cfs (Oct. 3, 1938). Average discharge over 66 years of record (water years 1898-1901, 1919-1980) was 1506 cfs. High flows in the river result from winter rains and spring snowmelt. Exhibit 3 (Appendix B) is a hydrograph of monthly peak flows for the 10-year period 1971-1980. This hydrograph indicates spill will occur most of the year except for the late summer and early fall months, or during dry years similar to 1977.

Dam Operations

Both Elwha and Glines Canyon Dams are run-of-the-river type dams, i.e., dams having small storage capacity and therefore passing most of the natural river flow. Presently both dams are operated to maintain maximum head on the turbines (elevation 610 M.S.L. at Glines Canyon Dam and elevation 188 M.S.L. at Elwha Dam). This type of operation results in minor overtopping of the spillway gates from a relatively small change in river flow. Gate operation records provided by the CZ, owners and operators of the dams, indicate that an effort is made to control overtopping of the gates by opening gates. However, the presently maintained forebay elevation is usually too high to prevent some overtopping.

Glines Canyon Dam turbines and gates are operated to provide 1750 cfs of streamflow, when available. This allows operation of the Elwha Dam facility at full power generation. All four generators are operated at Elwha Dam until stream flow falls consistantly below 800 cfs, usually during the period August through October. A minimum stream flow of 350 cfs is maintained one mile downstream of the dam. At normal flows, full generation is carried if demanded by the CZ mill requirements. If less than full generation is required for the mill, or if stream flow is higher than required for full generation, the reservoirs are filled to capacity and surplus water is discharged through the spillway gates. For flood flows, the forebay at Glines Canyon Dam is drawn down 5 feet, and the forebay at Elwha Dam is drawn down 2 feet, in advance of the pending flood.

Appendix C contains a series of photos of the existing CZ facilities and related views around the spillways. Also shown are photos of successful passage facilities located on other rivers.

PROPOSED MODIFICATIONS, ALTERNATIVES, NEW STUDIES

The remaining discussion addresses the final three investigation topics, i.e., operational/facility changes needed for fish passage, alternatives for implementing changes, with associated costs, and new monitoring studies with fish passage.

Facilities Proposed for Fish Passage

I. Upstream Passage Facilities

Since both dams are high--Elwha Dam 100 feet and Glines Canyon Dam 190 feet--construction of a complete fish ladder to by-pass adult salmonids would be very costly. Current cost for fish ladder construction is about $15,000 per foot of vertical lift. Therefore, a complete fish ladder is not recommended for passage at either dam.

The method we recommend to pass adults is to construct and operate a trap-and-haul type facility at both dam sites. Following capture, adults would be transported to areas upstream of the respective dams by way of a hopper-cable-truck system. Exhibits 4 and 5 (Appendix B) are schematic diagrams showing approximate size and location of facilities proposed for the capture and movement of adult salmonids at the Elwha Dam site.

The facilities proposed consist of an entrance pool with a diffuser system to introduce auxiliary attraction flow, a short pool-and-weir type ladder, a "V" trap, a holding chamber with a crowder, and a hopper and cableway system to lift fish to a truck for transport to release sites located upstream of the respective dams. Elwha Dam facilities would require a fish sorting chamber to be used in conjunction with a monitoring program. In the sorting chamber, technicians would record the species, physical measurements, and any sampling marks among returned adults. The hopper and cableway at Elwha Dam would provide the option of either loading fish into a truck or releasing fish directly into the forebay.

A velocity type barrier dam would be constructed in the channel exiting from the right bank spillway of Elwha Dam. It would prevent upstream passage of fish into this area and guide fish to the ladder entrance. Water leaking around the right abutment would be collected behind this dam and diverted through a pipe system for use in the operation of the upstream fish passage facilities. Exhibit 4 (Appendix B) shows the proposed location of the barrier dam.

II. Downstream Passage Facilities

A. Physical Changes

Recommended downstream passage facilities at Elwha Dam would consist of installation of pressure type Eicher screens in the 15-foot penstock and the two 9-foot 6-inch penstocks. Low flow by-pass pipes would then be used to transport screened fish to the tailrace area. Exhibit 6 (Appendix B) shows a typical screen installation. Improvement of juvenile fish passage down the left spillway would be accomplished by removing the large projecting rock formations and applying gunnite concrete over the entire spillway surface to minimize abrasion.

No physical changes are recommended for Glines Canyon Dam at this time. If fish runs are re-established on the upper river, future monitoring and analysis of juvenile mortalities may indicate the need for screening the penstock intake at Glines Canyon Dam. This could be easily accomplished at that time, if deemed necessary.

B. Operational Changes

To reduce descaling injuries at both dams, we recommend that reservoir levels be held at least 6 inches below the top of the spillway gates. This would result in a minimum forebay elevation of 609.5 m.s.l. at Glines Canyon Dam and 187.5 m.s.l. at Elwha Dam. This change would minimize occurrence of overtopping the gates due to small increases in inflow to the reservoir.

During the general smolt emigration period, March through August (see Figure 2), water should be spilled on a daily basis at Glines Canyon Dam to prevent or minimize the possibility of smolts sounding and exiting through the penstock. The amount and timing of these spills could be determined by studying the emigration pattern of the juveniles during the first few years of operation. Water should be available for this purpose in most years, as shown by Exhibit 3 (Appendix B).

Other operational changes can be made, as necessary, to provide safe passage for juvenile fish and keep mortality and physical injuries to a minimum. In particular, during the general smolt emigration period, turbines should be operated at an efficient level (75% wicket gate opening) to reduce smolt injury/mortality.

Expected Salmonid Survival Rates

The proposed passage measures described above should result in increased outmigrant survival. Survival rates can be expected to vary by species. It appears reasonable to predict that implementation of improved dam operations at both dams, and smoothing the Elwha left spillway, should result in 80%+ survival of coho juveniles. These changes should result in juvenile chinook survival that is as good as or better than coho. Conversely, steelhead smolts, due to their larger size, would probably experience somewhat lower survival than coho. The construction and maintenance of Eicher fish screens at Elwha Dam should result in additional, respective survival rate increases of about 10%. The completion of all measures should result in a coho survival rate of about 90%+. The respective rate for chinook may be yet higher while that for steelhead will likely be somewhat lower.

Proposed Alternatives for Implementation of New Measures

I. Alternative A: Full and Immediate Implementation

Alternative A addresses all upstream and downstream fish passage requirements as one comprehensive project. It assumes that production of fry and smolts from upstream rearing will be adequate. Upstream adult passage requirements, under Alternative A, would be met by implementing the following:

at Elwha Dam,

(1) constructing and operating a short ladder and a fish trap at the foot of the dam, with associated chambers for holding and sorting adults,

(2) constructing and operating a fish hopper, suspended from and conveyed by a cable leading to a loading area on top of the dam,

(3) constructing a loading area for the fish truck on top of the dam,

(4) constructing and maintaining an adult barrier weir at the foot of the right (east) spillway to block straying adult fish,

(5) constructing and maintaining a truck ramp for fish releases on Lake Aldwell, and

(6) purchase and operation of two fish transport trucks;

at Glines Canyon Dam,

(1) construction and maintenance of a barrier dam in the vicinity of the Glines Canyon power plant,

(2) construction and operation of a fish trap adjacent to the barrier dam, with associated chambers for holding and sorting adults, and

(3) construction and maintenance of a truck ramp for fish release on Lake Mills.

Downstream fry and smolt passage requirements, under Alternative A, would be met by implementing the following:

at Elwha Dam,

(1) constructing and maintaining Eicher fish screens inside all power plant penstocks, with associated flumes to transport diverted emigrant fish safely to the river below the dam,

(2) modifying the left (west) spillway to reduce hazards to passing emigrant fish,

(3) eliminating use of the right spillway for spilling, except for periods of emergency spill when the structural integrity of the dam may be endangered, and

(4) operating the dam to reduce causes of fish injury/mortality through efficient turbine operation (an estimated wicket gate opening of 75%), improved spillway gate scheduling, and minimized dam overtopping, and

(5) monitoring survival, after dam passage, of each emigrating salmonid species during the initial year (s);

at Glines Canyon Dam,

(1) operating the dam to reduce causes of fish injury/mortality through improved spillway gate scheduling and minimized dam overtopping.

II. Alternative B: Phased-in Implementation

Alternative B would address, in stages, the same fish passage requirements addressed under Alternative A. Alternative B would be more conservative of initial expenditure. It would evaluate production of fry and smolts resulting from upstream spawning and rearing. Alternative B would be organized into three phases, with each subsequent phase contingent upon the success of the preceding phase.

Phase One (years 1 and 2) would consist of the following:

(1) introducing fish above the dams by one or more temporary methods (e.g., adult trap and transport, fry plants),

(2) evaluating the survival of emigrating fry/smolts resulting from upriver fry planting or adult spawning,

(3) modifying the left spillway at Elwha Dam to reduce hazards to passing emigrant fish,

(4) eliminating use of the right spillway at Elwha Dam for spilling, except for periods of emergency spill when the structural integrity of the dam may be endangered, and

(5) operating both dams to reduce causes of fish injury/mortality through operation of the turbines at an efficient level (an estimated wicket gate opening of 75%), improved spillway gate scheduling, and minimized dam overtopping.

Phase One (years 2 through 5) would consist of the following:

(1) at Elwha Dam, construction and operation of an adult barrier weir, a short ladder, a fish trap, a cableway with a hopper, and a fish truck loading area,

(2) construction of truck ramps for fish releases on both reservoirs,

(3) purchase and operation of two fish transport trucks, and

(4) continued evaluation of downstream migrant survival.

Phase Two (years 4 and 5), contingent on the general success of the preceding phase, would consist of:

(1) construction of a barrier dam and an adjacent fish trap downstream of Glines Canyon power plant.

Phase Three (year 5 +), contingent on the general success of Phases One and Two, would consist of the following:

(1) construction and maintenance of Eicher fish screens inside all Elwha Dam penstocks, with associated fish transport flumes.

Cost of Alternatives

Evaluation of Alternatives A and B must be performed on the basis of cost as well as objectives and caution. The estimated cost of completing all steps under alternative A, less engineering and contingency costs, is $2,951,000. The estimated cost of alternative B would depend on the number of work phases undertaken. However, if all Alternative B phases are completed the total cost would be the same as for Alternative A, in 1984 dollars. Alternative A makes an immediate and full commitment to completing all measures for both upstream and downstream passage. Measures and construction under Alternative B would be phased, in an orderly manner, as their use becomes necessary or is deemed economically feasible. Following is a proposed schedule for phased construction (also see Exhibit 7, Appendix B) 1/.

Phase One (Year 1)	* Modify operations at Elwha and Glines Canyon Dams 2/.	
	* Remove rock outcroppings and gunnite left spillway at Elwha Dam	
	Year 1 construction costs	$159,000

1/ Construction costs shown do not include engineering and contingency costs.

2/ No dollar loss to CZ as a result of modified operations is included in this estimate.

Phase One (Years 2-5)	* Construct upstream migrant facilities at Elwha Dam, and barrier dam downstream of Elwha Dam * Construct release ramps at both reservoirs * Purchase 2 fish transport trucks Years 2-5 constructions costs	$980,000
Phase Two (Years 4-5)	* Construct migrant facilities and barrier dam downstream of Glines Canyon Dam Years 4-5 construction costs	$860,000
Phase Three (Year 5 +)	* Construct and install Eicher fish diversion screens in Elwha Dam penstocks Year 5 + construction costs	$952,000
	Total Construction Cost for All Phases	$2,951,000

Proposed New Studies

Implementation of either of the proposed alternatives would, hopefully, lead to restoration of anadromous runs, but it would also create a need to monitor success of the various passage measures. Several of these measures, if not all of them, rest on the assumption that what has worked in another river or lake will work on the Elwha. To accept some of these assumptions may be reasonable, however, others require verification by futher studies.

I. Adult Capture

While new fish passage facilities at either of the Elwha dams would be the product of careful research and engineering, only actual operation of the various adult capture facilities would serve to prove or disprove the success of each one. The barrier weir, ladder, and trap each would require a specific range of flows to work effectively, and this could vary among the different adult species as well. Very critical for success of the ladder and trap (and adult capture entirely) is attraction flow. Attraction has been a persistent problem at some adult capture facilities. At both Elwha dams adequacy of adult attraction should be verified for each species. Verification could simply be a matter of recognizing that certain flows through the ladder and trap result in marked increase in adult entry. The worst case of non-attraction could require downstream capture and radio tagging of a test group of adults to determine where they ultimately go in relation to the attraction flow. Water turbidity and high flow velocity would likely eliminate snorkel or scuba diving as an appropriate method to locate adults below the trap.

Other features of the adult capture facility proposed for Elwha Dam are unlikely to pose a problem. Should a problem be detected in either the sorting chamber, hopper and cableway, fish loading facility, or the fish transport truck, it is unlikely to require formal study. Such problems would most likely be solved by performing minor modifications. Location of the truck ramp for fish release, however, could potentially lead to incidence of adult fallback over the dam if the location is not sufficiently distant from the dam. Should adult fallback be detected through frequent recycling at the trap, then the problem will require study to find a suitable location for lake (or river) release.

II. Smolt and Fry Emigration Past the Dams

New operating procedures and/or modifications at both dams should result in reduced mortality and injury to downstream migrants. To assess the effectiveness of the recommended passage measures in reducing emigrant mortality, a monitoring program should be initiated. The monitoring program would include, but not be limited to, the following activities.

A. Elwha Dam

Available information indicates that juvenile passage problems are greatest at Elwha Dam. In 1985, FAO has proposed developing a salmonid survival model for ONP that would provide stochastic estimates of the numbers of outmigrants passing Elwha Dam and their survival. These estimates would be developed by collecting and coded wire tagging (CWT) smolts passing Lake Aldwell, and then hydrosonically monitoring their passage through the various exits in Elwha Dam. Eventually, survival (indicated by adult CWT recoveries) would be correlated with exit conditions at time of passage. This would provide the most complete measure of the effects of passage on long-term survival, and would identify the need for further changes, if any, in dam exits or operating procedures.

Short-term assessments, however, would be useful for early indications of the effectiveness of the proposed passage measures at Elwha Dam. These assessments would include tests of the left bank spillway after smoothing, and the survival of other species (e.g., steelhead) through dam exits. If the penstocks are screened, subsampling migrants in the bypass flume(s) would provide immediate indications of the effectiveness of the screening operation.

B. Glines Canyon Dam

The most complete measure of the effects of passing Glines Canyon Dam and then Elwha Dam would be application of a salmonid survival model similar to that described above. Collection, CWT and hydrosonic monitoring would occur at the upper facility rather than the lower reservoir and dam. As above, CWT recovery data would form the basis for determining needed changes in dam exits and operating procedures.

Several data gaps exist for Glines Canyon Dam that are important in the monitoring program. They should be examined sooner, on a more limited scale. These data gaps include: choice of exit for migrants (particularly steelhead and chinook) under varying spill and generation conditions; survival of other species (e.g., steelhead) through Glines Canyon Dam exits; and the possible incidence of gas supersaturation, sudden decompression, or thermal shock to downstream migrants at this facility.

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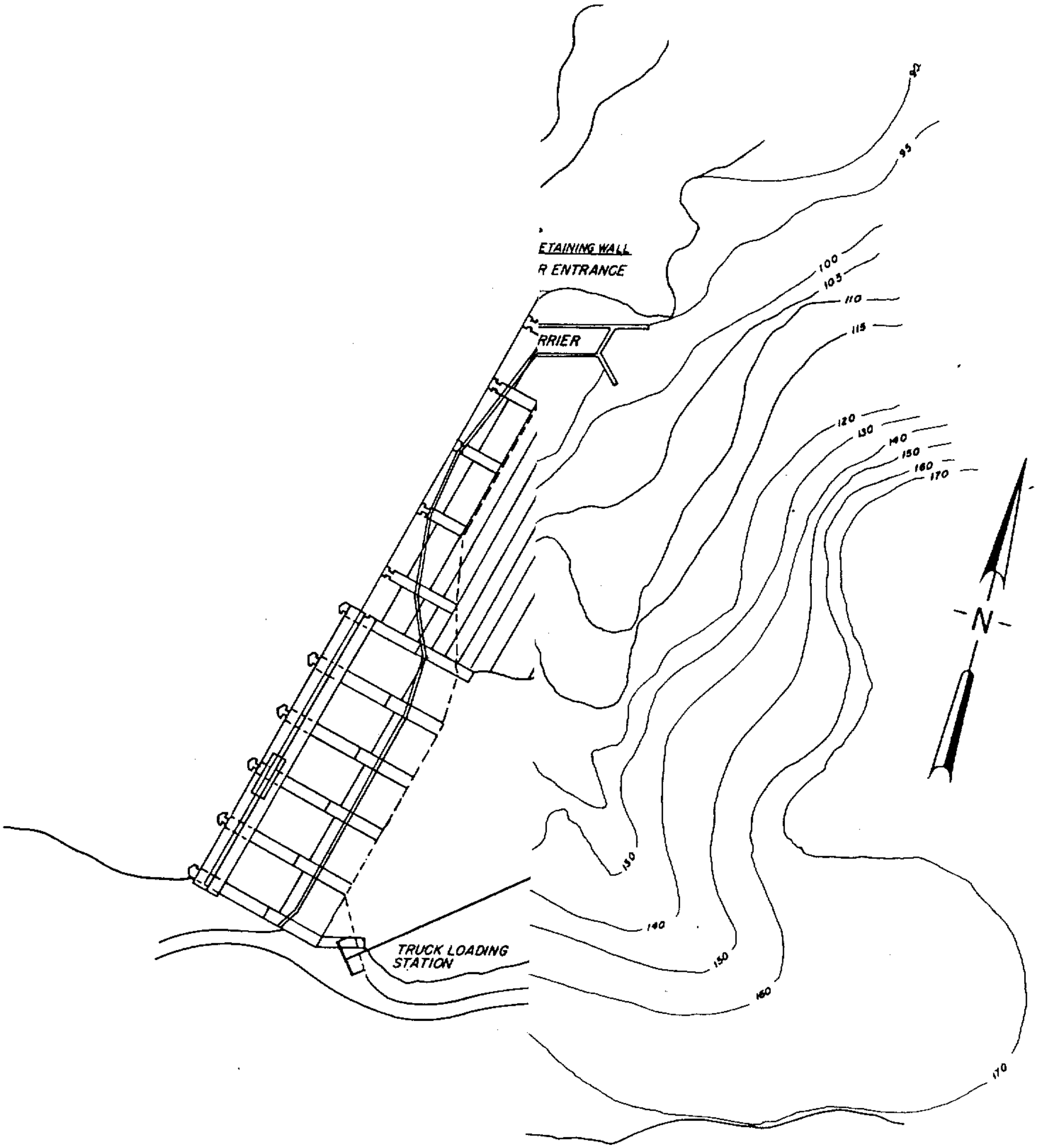
ETAINING WALL
R ENTRANCE
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TRUCK LOADING STATION
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95
100
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APPENDIX A.

Interpretation of FAO 1984 Trapping Data and Related Information

I. Chinook Salmon

When trapping began in late April 1984, numerous wild chinook fry having mean fork lengths (FL) of about 42 mm, were being captured daily (Table 1). We assume these were primarily summer-fall chinook. Trapping during May, June, and early July produced chinook having mean FL of 84 mm, 89 mm, and 84 mm, respectively. By mid-May the frequency of age 0 chinook captures was much reduced, but the capture frequency for larger, older chinook had increased dramatically. This is reflected by the secondary modes listed in Table 1. The data in Table 1, particularly that for FL mode values, by month, may provide the most reliable information on chinook emigrants to be used at the dams during the period April to July.

Review of the data for time of capture showed that there were very few chinook migrating in daylight during late April (1%). However, during subsequent trapping in May, June, and early July, this daylight migration rate increased markedly to 8%, 33%, and 54%, respectively (Table 2). Reimers (1971) found that fry migrated primarily during darkness and avoided migration under moonlit conditions. Higher stream flow in the Elwha, during late spring and early summer, increased turbidity. This turbidity likely contributed to increased movement during daylight.

II. Coho Salmon

The mean FL of coho emigrants captured by FAO were: 110 mm in late April: 134 mm in May; 143 mm in June; and 131 mm in early July (Table 1). While it is possible that some FAO-released hatchery smolts may have been among these wild emigrant fish (due to unrecognizable brands), the mean FL values compare relatively well with respective mean FL values from other streams. During 1982 and 1983 the WDF (Bill Wood, WDF, personal communication) trapped coho smolts in tributaries of the Quillayute River. Mean FL from all streams, in all months of trapping, ranged from 96 mm to 126 mm, with an overall combined mean FL of 111 mm. Such variation in mean FL was attributed to differences in seasonal water temperature from year to year, survival levels, and relative seeding levels.

As with chinook emigrants, the percentage of coho emigrants moving during hours of darkness was high in late April (86%) and generally declined until trapping ended during early July (67%) (Table 2). Again, stream flow and associated turbidity may have influenced day vs. night movement.

III. Winter Steelhead Trout

Juvenile steelhead mean FL ranged from 187 mm in May to 216 mm in July (Table 1). A distinct peak in number of smolts trapped occurred during May. It appears that they had begun to emigrate in early to mid-April and they stopped in early July. In comparison, steelhead emigration data collected at Snow Creek Research Station (WDG 1978; 1979) indicates smolts there were smaller -- combined mean FL range was about 145 mm to 191 mm -- and their migration timing appears to have been more advanced by one or two weeks.

Past research demonstrated that steelhead smolts move downstream during both day and night, with their most rapid movement occurring during twilight hours (Royal 1973). Analysis of the 1984 FAO emigrant trapping data showed that a majority of steelhead moved during hours of darkness during all months of trapping. Capture during darkness in late April, May, June and early July was 79%, 91%, 76% and 88%, respectively (Table 2).

Steelhead kelt downstream migration can be expected (at the dams) about the same time that smolts are emigrating (Royal 1973).

IV. Summer Steelhead Trout

Review of the literature indicates no significant difference exists between the period of emigration of summer steelhead smolts and that of winter steelhead smolts. The FAO trapping data for steelhead emigrants, described above, provide the best indication of summer steelhead emigration timing and fish size needed to guide fish protection at the dams.

V. Sea-Run Cutthroat Trout

The literature indicates that sea-run cutthroat smolts can be expected to begin emigration during April and continue until June (Royal 1973; WDG 1978; 1979). At the Snow Creek Research Station smolt and pre-smolt FL ranged from about 115 mm to 251 mm. Cutthroat kelts migrate downstream during the same general time period as that for smolts.

VI. Spring Chinook Salmon

Spring chinook fry emerge from the gravel and may remain in the stream only a few months prior to emigrating during the spring run-off period. However, some juveniles emigrate later during summer months while others remain for one additional year, emigrating during the following spring run-off (Chapman 1979; Royal 1973). Williams et al. (1975) defined emigration timing for Dungness fish which appears to be the best guidance for the Elwha (Figure 2). Smolts may emigrate at lengths of 85 mm to 120 mm. Outmigration timing of wild spring chinook in Puget Sound is not completely known, and may vary within and among different stream systems from year to year. Information on one system, the Nooksack River, suggests that the majority emigrate as spring subyearlings (Wunderlich, FAO, personal communication).

VII. Pink Salmon

Pink salmon fry emerge from the gravel from late winter to early spring, measuring from 28 mm to 32 mm (Chapman 1979). They emigrate to saltwater almost immediately following emergence. Williams et al. (1975) probably provided the best indication of fry emigration timing to use in the Elwha, and this is shown in Figure 2.

APPENDIX B.

Information and Diagrams, Exhibits 1-8

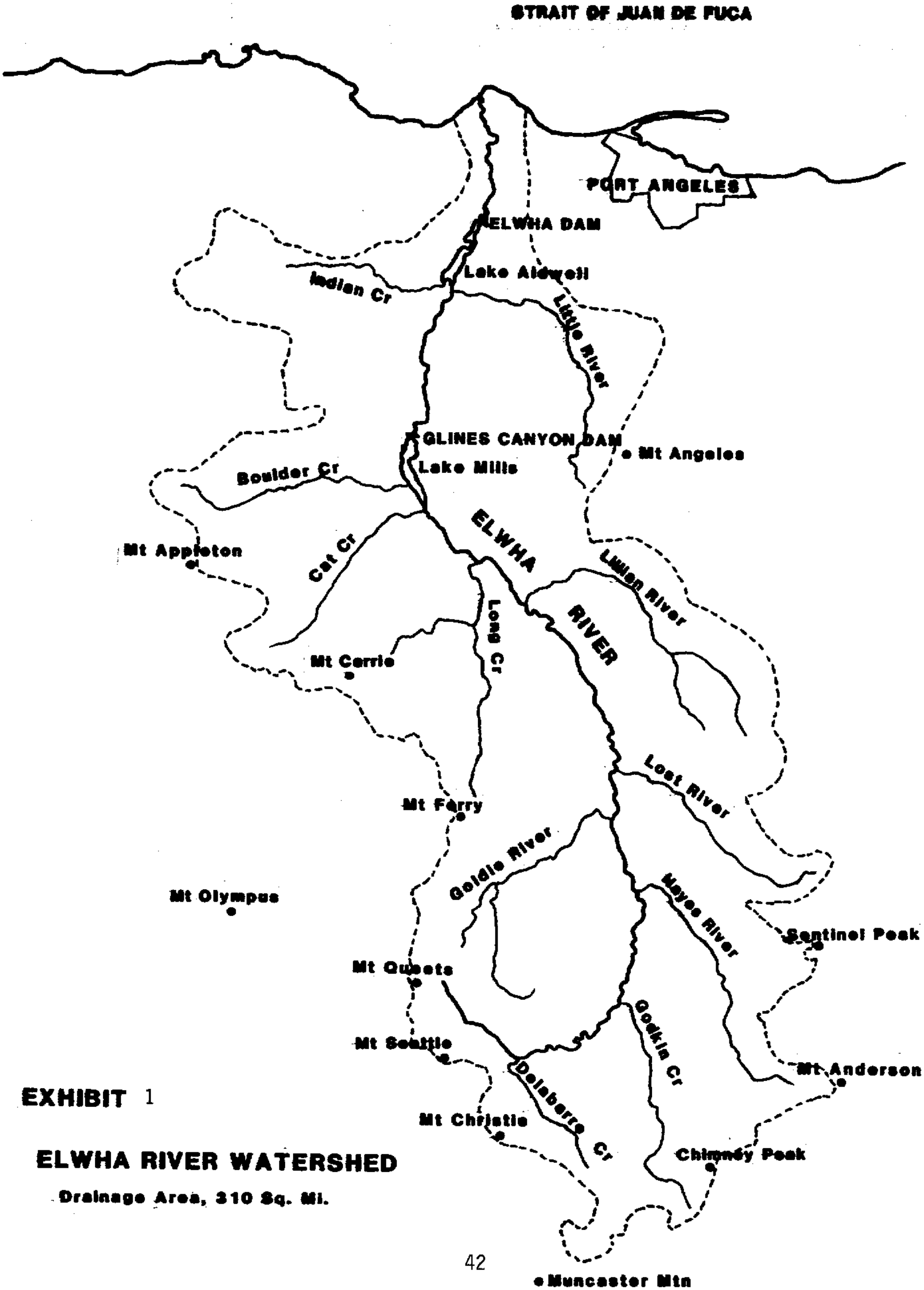


EXHIBIT 1

ELWHA RIVER WATERSHED

Drainage Area, 310 Sq. Mi.

ELWHA RIVER MEAN MONTHLY FLOWS-CFS

USGS Gage 12045500 McDonald Bridge near Port Angeles, WA

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	MONTHLY AVERAGE
JANUARY	2003	1372	2064	3717	1789	2644	781	1595	424	1700	1809
FEBRUARY	2294	1894	958	1560	1137	1481	893	1327	1232	2435	1521
MARCH	1524	3307	1028	2122	1188	972	929	1220	1819	1455	1556
APRIL	1398	1753	695	1537	782	1112	1183	1067	876	1532	1194
MAY	2818	2601	1670	1965	1726	2323	1301	1372	1843	1708	1933
JUNE	2818	3022	1757	3752	2641	2268	1589	2041	1603	1629	2312
JULY	2876	2470	1181	2759	2018	2357	779	1335	1097	1134	1801
AUGUST	1642	1202	661	1593	1111	1283	680	743	542	549	1001
SEPTEMBER	782	788	462	827	707	721	596	1035	682	542	693
OCTOBER	657	538	715	468	2209	504	707	524	1008	406	774
NOVEMBER	1611	930	1490	1083	3573	574	2746	878	690	2501	1608
DECEMBER	1161	2368	2717	1934	4014	681	3191	764	5111	3834	2578
ANNUAL AVERAGE	1799	1854	1283	1943	1908	1410	1281	1158	1411	1619	

EXHIBIT 2

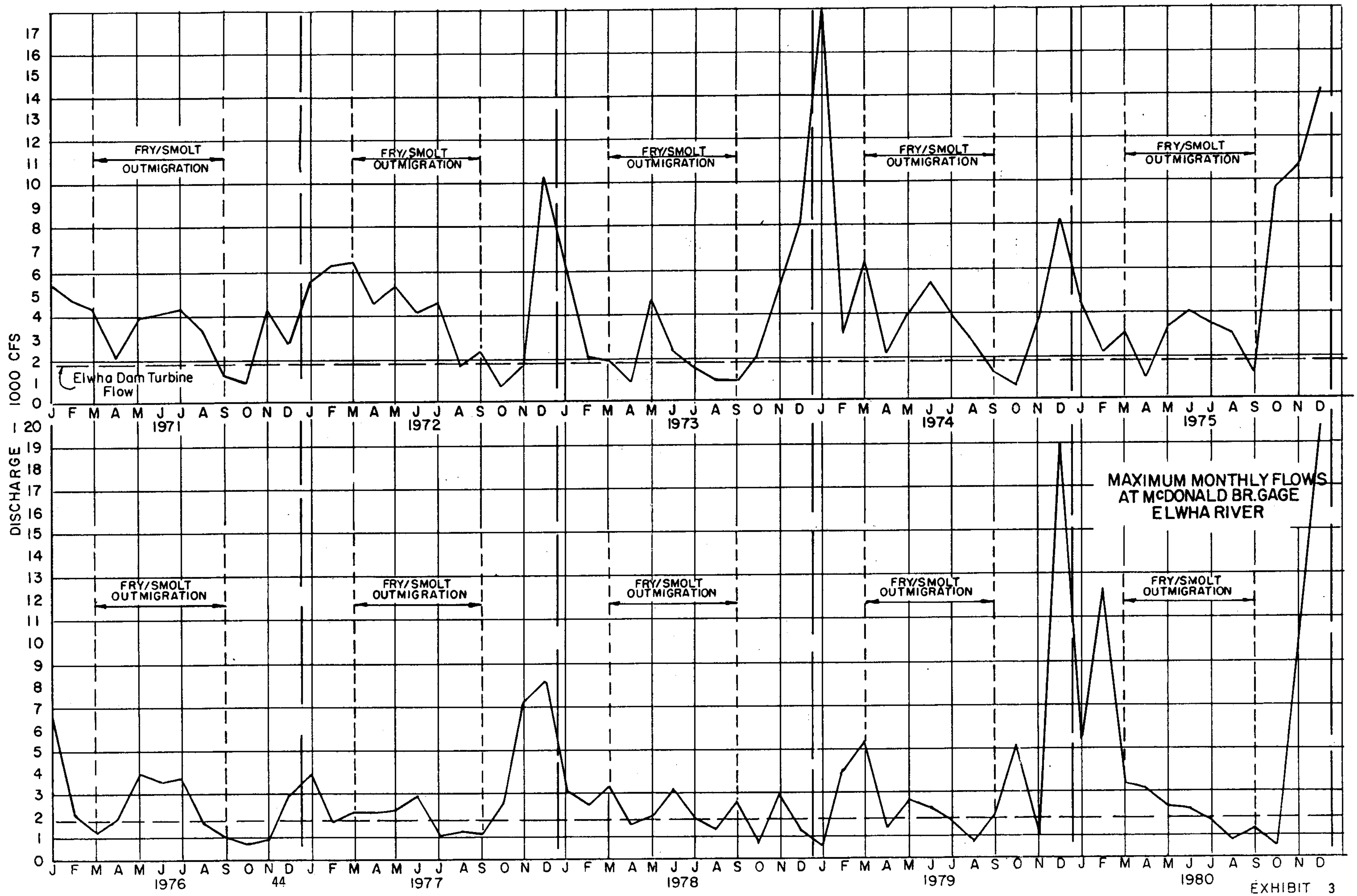
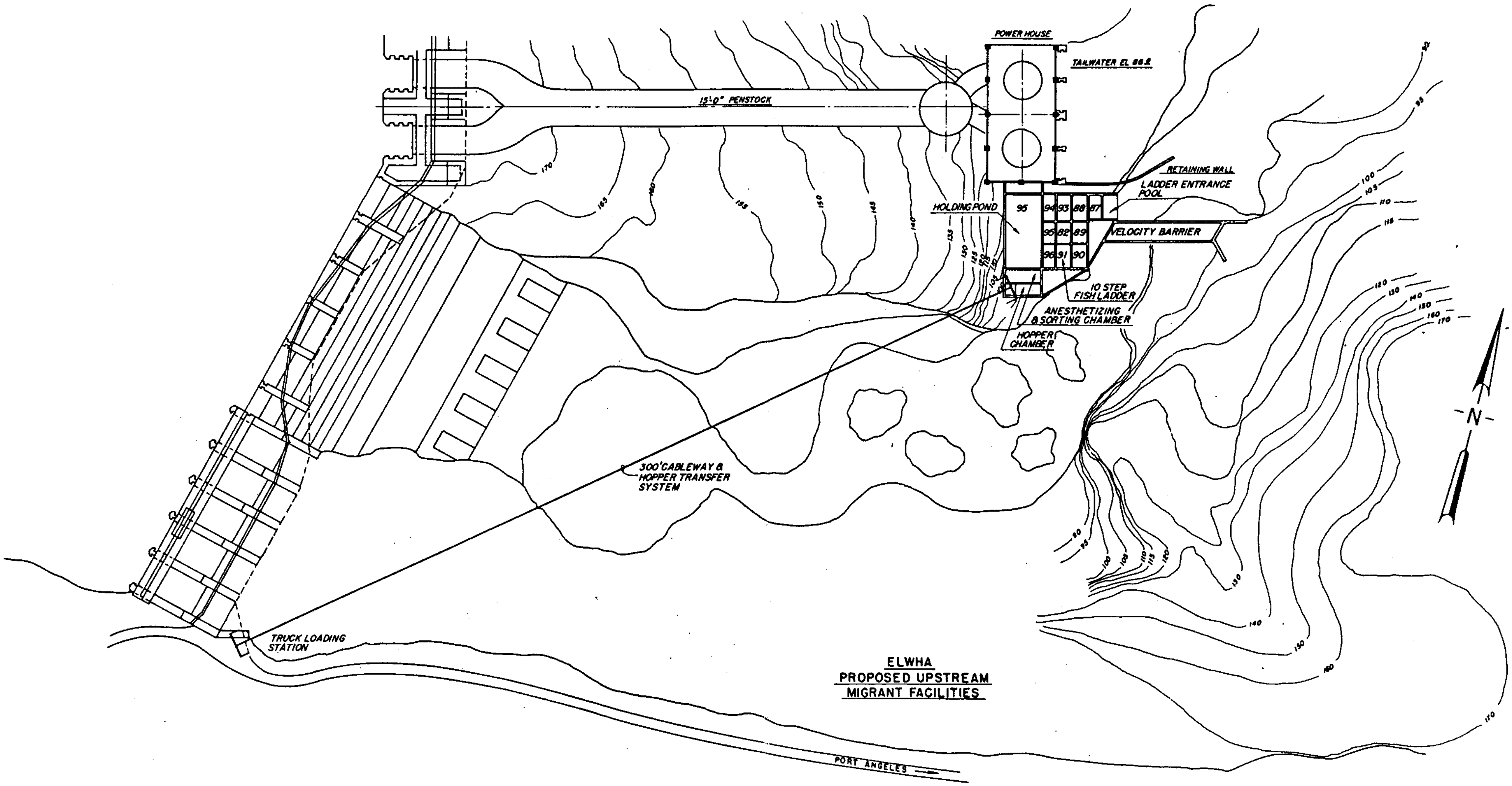

MAXIMUM MONTHLY FLOWS
AT McDONALD BR. GAGE
ELWHA RIVER
DISCHARGE - 1000 CFS
Elwha Dam Turbine Flow
FRY/SMOLT OUTMIGRATION
J F M A M J J A S O N D
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980

EXHIBIT 3

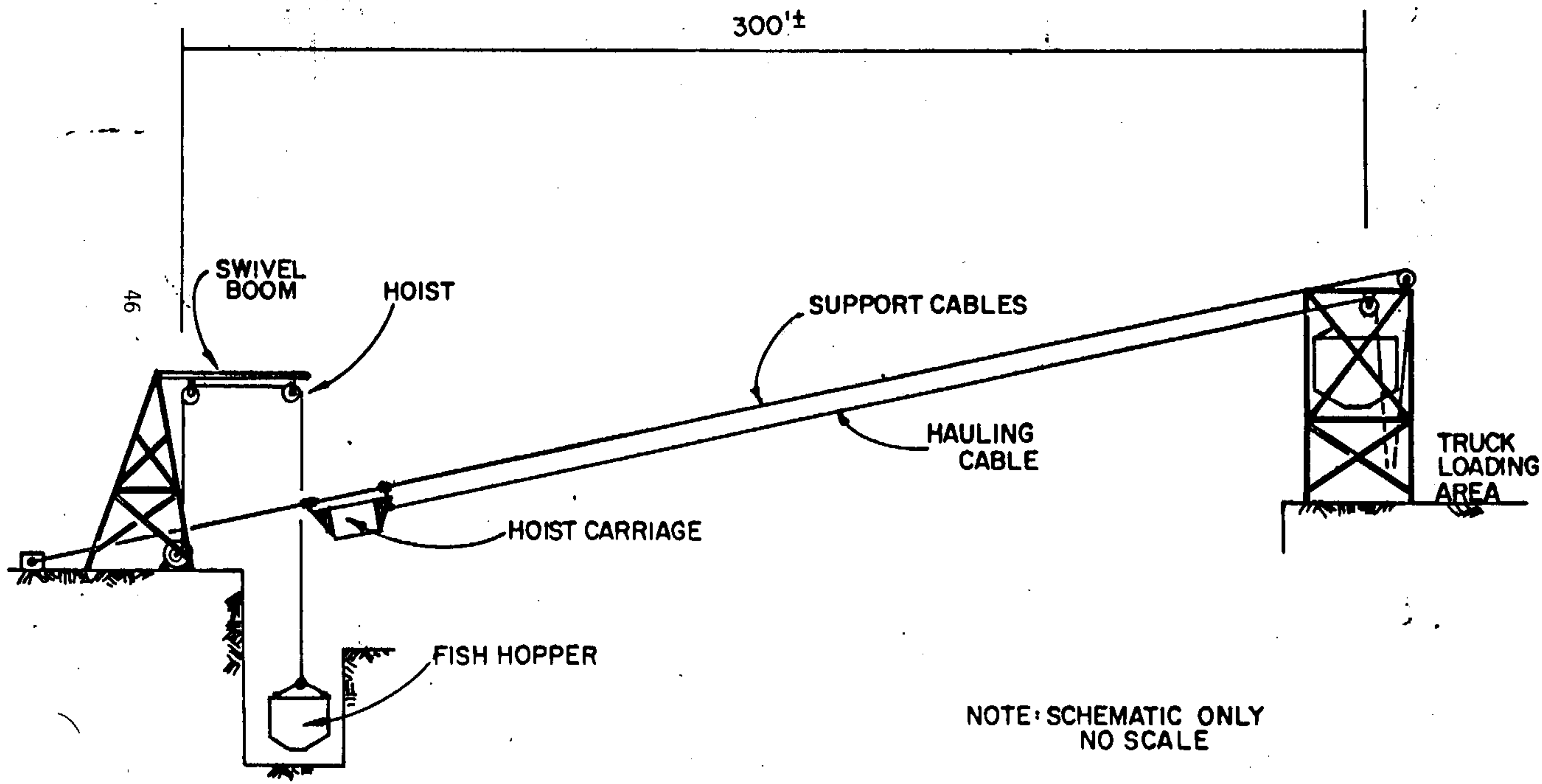


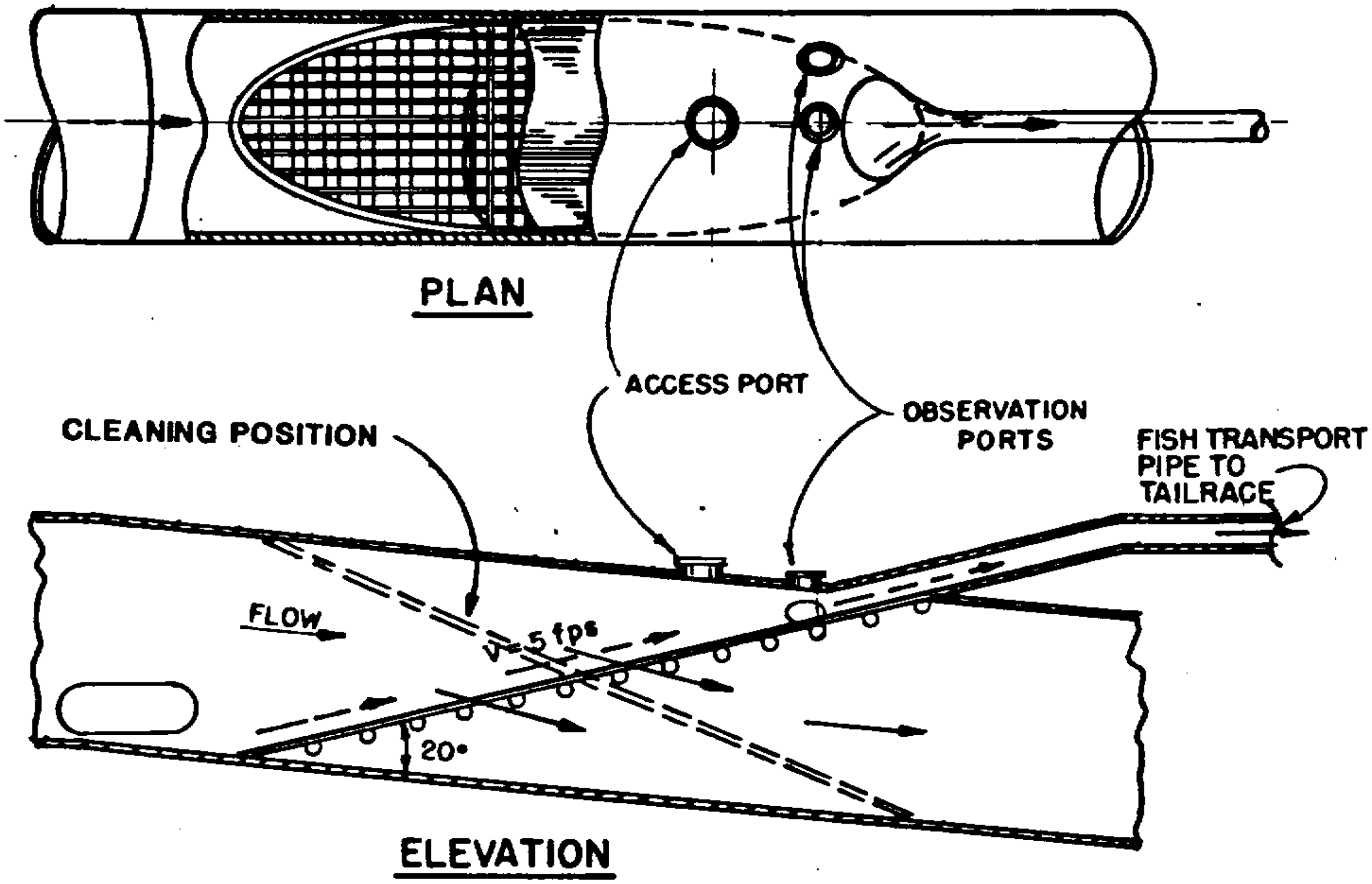
ELWHA
PROPOSED UPSTREAM
MIGRANT FACILITIES

EXHIBIT 4

EXHIBIT 5

CABLEWAY-HOPPER TRANSFER SYSTEM





TYPICAL PENSTOCK INSTALLATION FOR PRESSURE TYPE SCREEN

EXHIBIT 6

EXHIBIT 7

PROPOSED SCHEDULE OF CONSTRUCTION

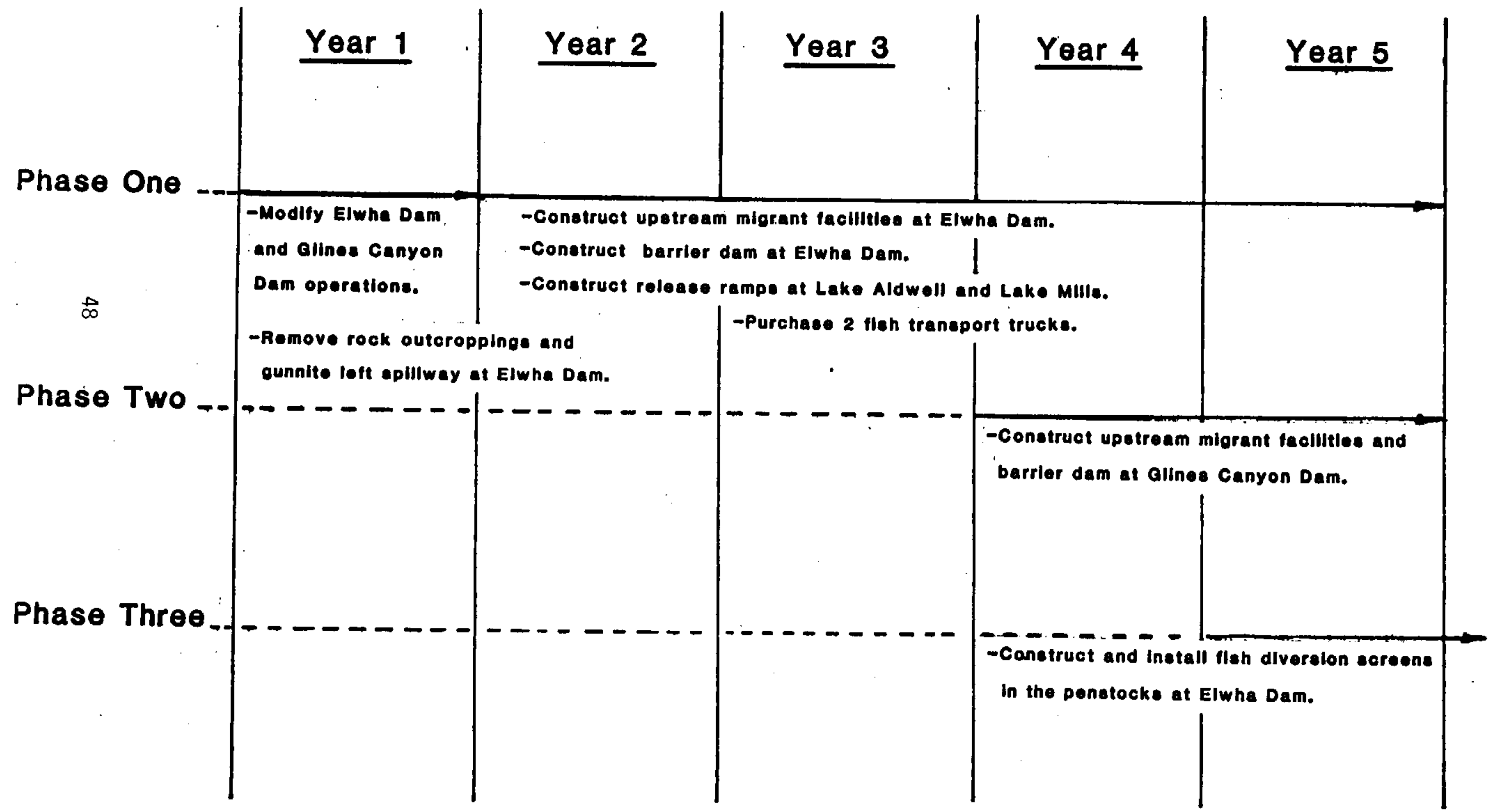


EXHIBIT 8

COST ESTIMATE FOR FISH PASSAGE FACILITIES

ELWHA DAM

Feature	Construction Cost
Fish ladder entrance pool	$ 30,000
10 step pool and weir type ladder	150,000
"V" trap or false weir	10,000
Holding pool	100,000
Crowder	50,000
Sorting chamber	30,000
Hopper chamber	30,000
Cableway - Hopper transfer system	250,000
Fish transport truck loading area	10,000
Lake Aldwell release ramp	20,000
Fish transport truck	40,000
Barrier Dam	200,000
Left spillway rock removal	5,000
Left spillway gunnite concrete	154,000
Pressure type fish screen for 15' Dia. Penstock	517,000
Pressure type fish screen for 2-9' Dia. Penstocks	415,000
Fish conveyance pipe for 3 Penstock screens	20,000
Subtotal	$2,031,000
Engineering and contingencies @ 33 1/3%	676,000
Total Elwha Dam Costs	$2,707,000

EXHIBIT 8 (cont'd)

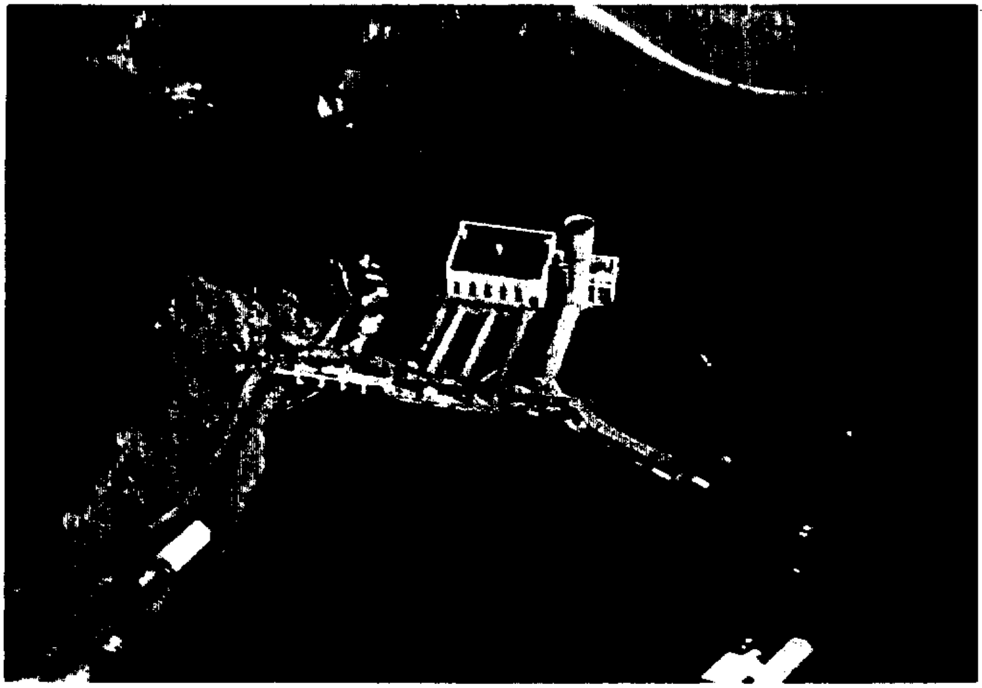
GLINES CANYON DAM

Feature	Construction Cost
Fish ladder entrance pool	$ 30,000
10 step pool and weir type ladder	150,000
"V" trap or false weir	10,000
Holding pool	100,000
Crowder	50,000
Sorting chamber	30,000
Hopper chamber	30,000
Cableway - Hopper transfer system	250,000
Fish transport truck loading area	10,000
Lake Mills release ramp	20,000
Fish transport truck	40,000
Barrier Dam	200,000
Subtotal	$920,000
Engineering and contingencies @ 33 1/3%	$306,000
Total Glines Canyon Dam Costs	$1,226,000
TOTAL ESTIMATED COST[1]	$3,933,000

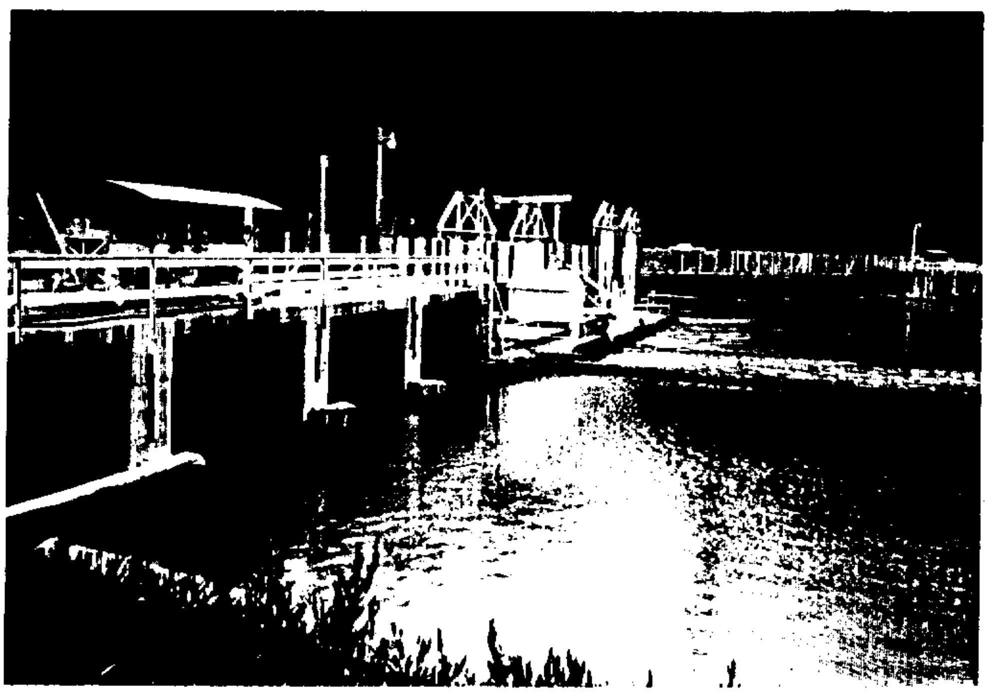
[1] ENR Cost Index 4158

APPENDIX C.

Photographs



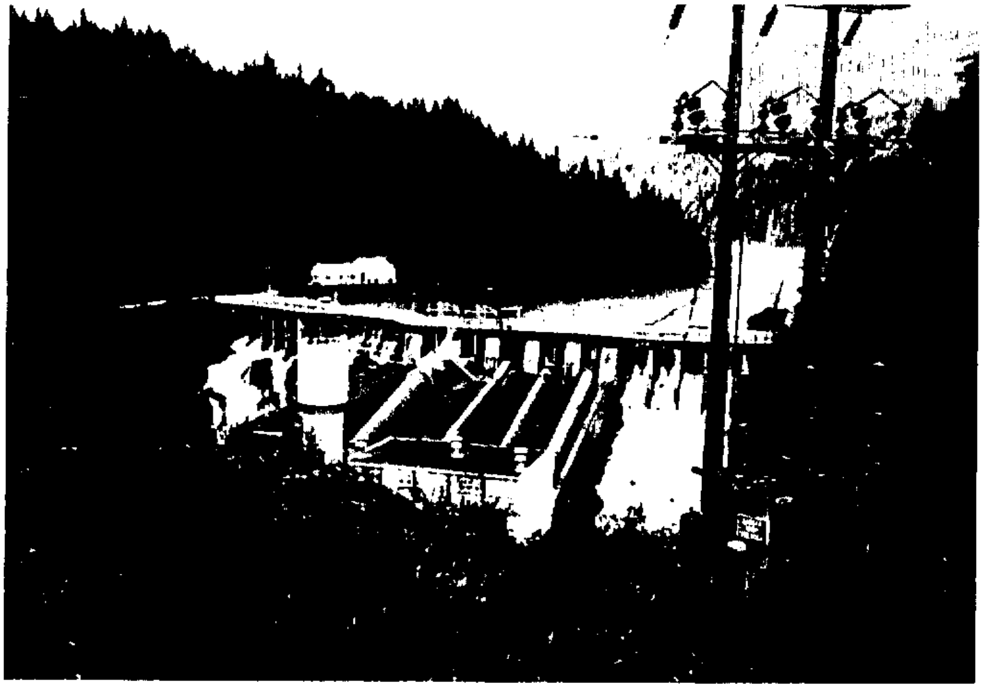
Aerial View of Elwha Dam



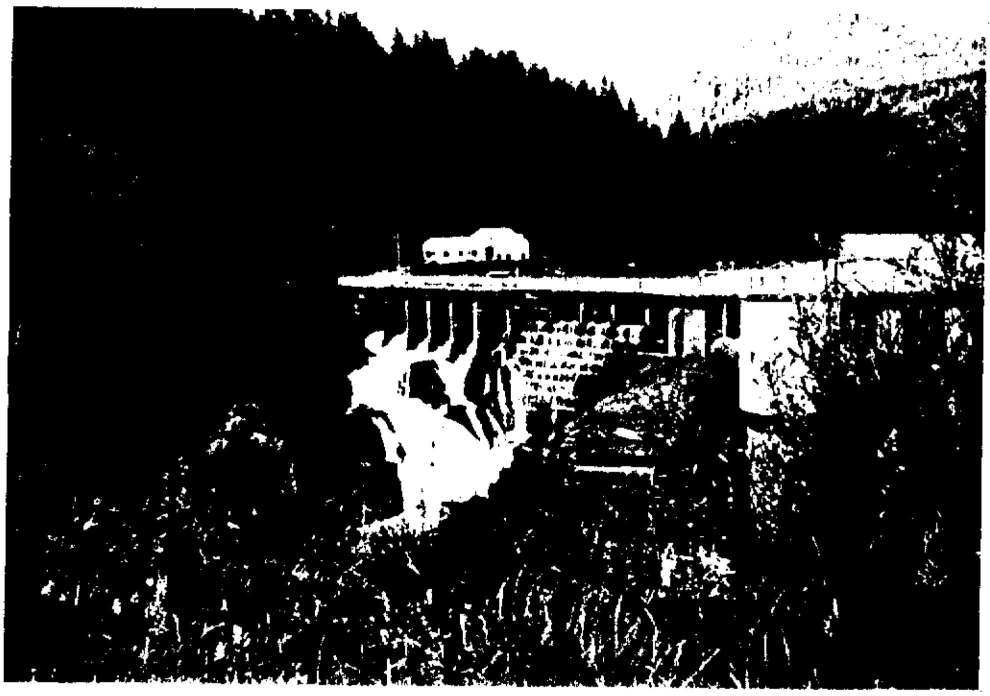
Elwha Dam Forebay

Elwha Dam Penstocks-Background 15' Dia., Foreground 9'-6" Dia.

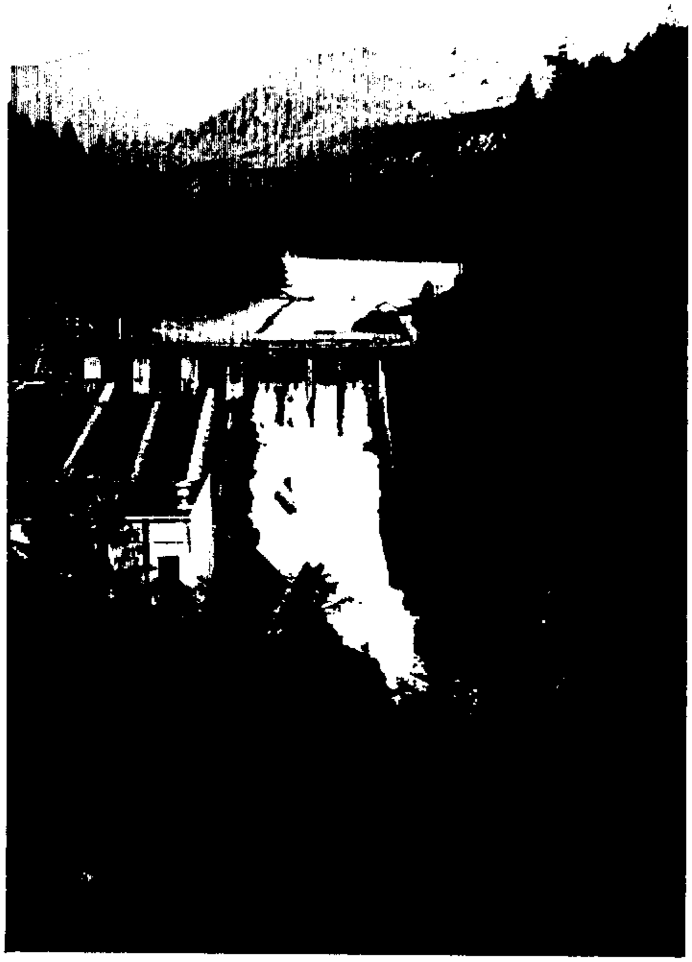
Elwha Dam Powerhouse Tailrace
Fish Ladder Entrance Will be Located at Left.



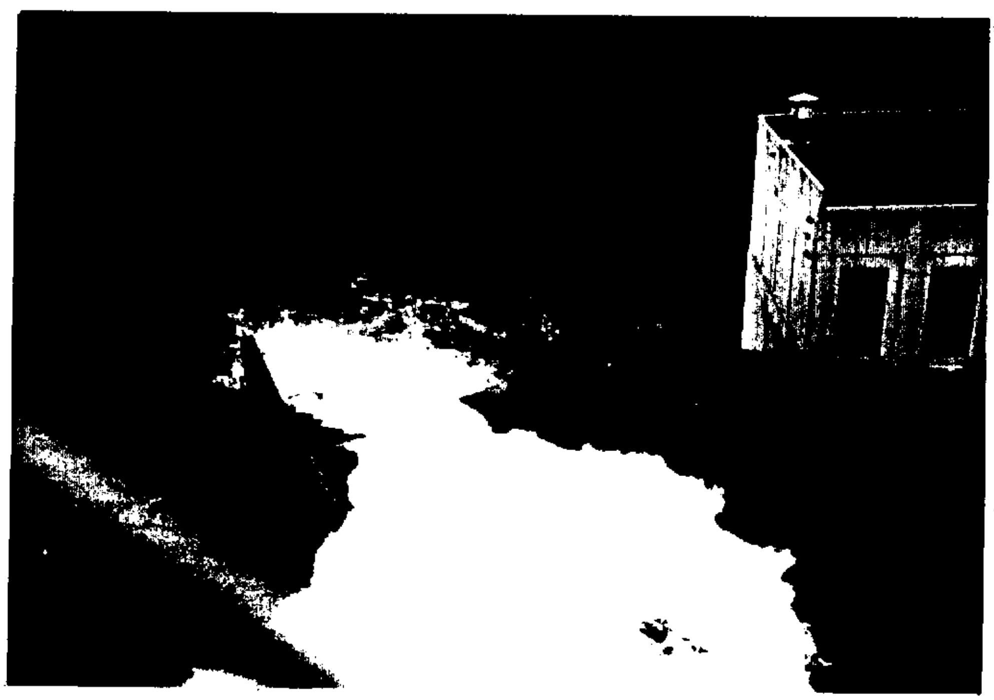
Panoramic View of Elwha Dam During Spill.



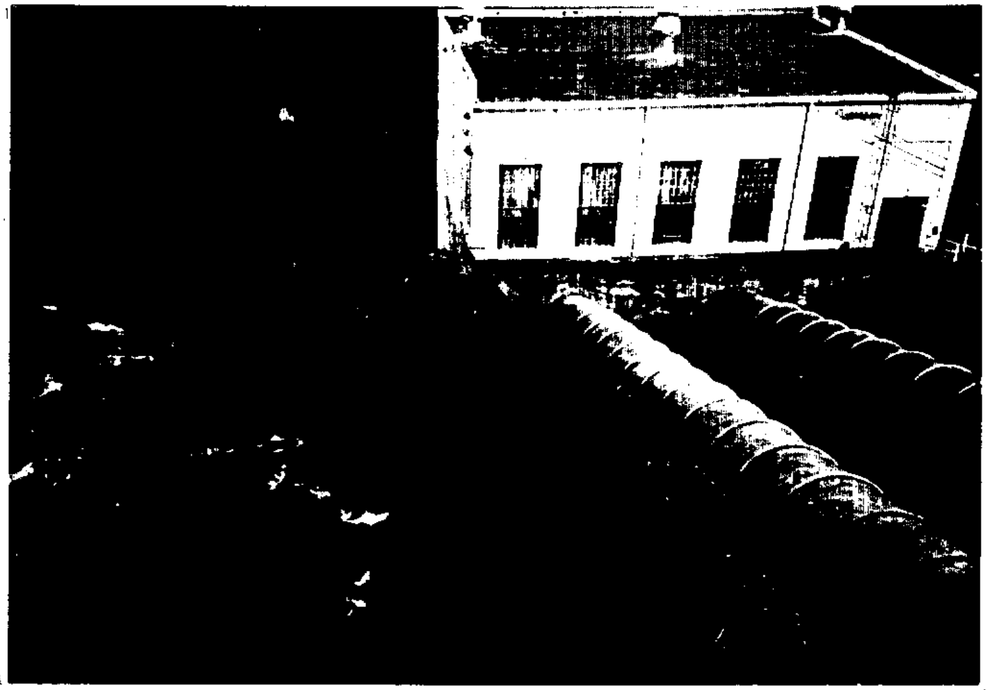
Elwha Dam - Right Spillway Section During Spill.



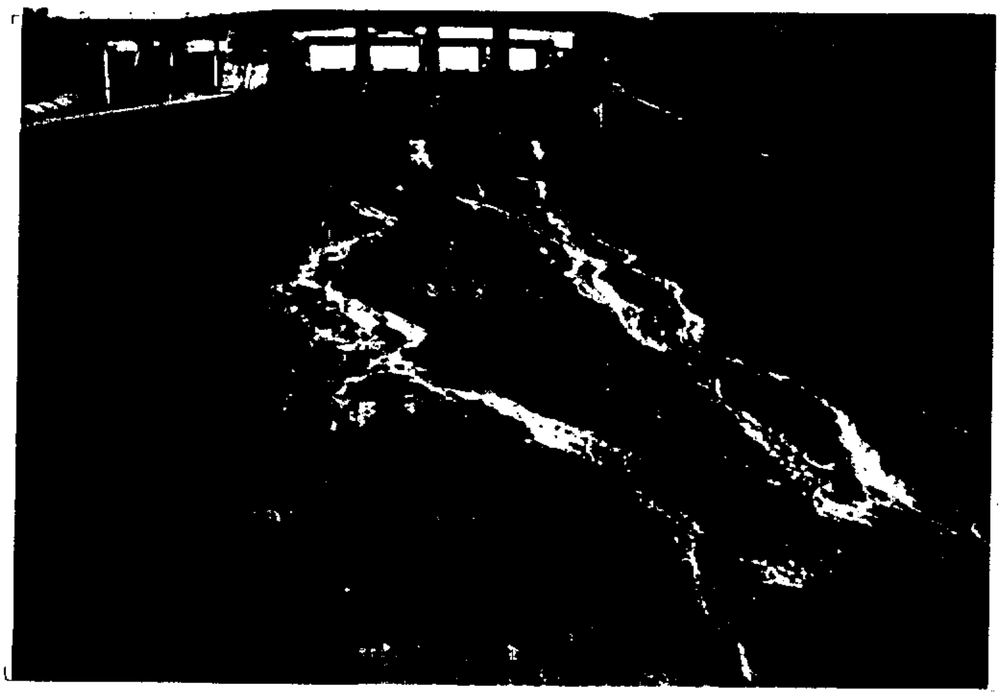
Elwha Dam-Left Spillway
Section During Spill.



Elwha Dam-Closeup of Left Spillway During Spill.



Elwha Dam - Closeup of Left Spillway No Spill.



Elwha Dam - Looking up Left Spillway.

Elwha Dam - Closeup of Rock Formations in Center of Left Spillway

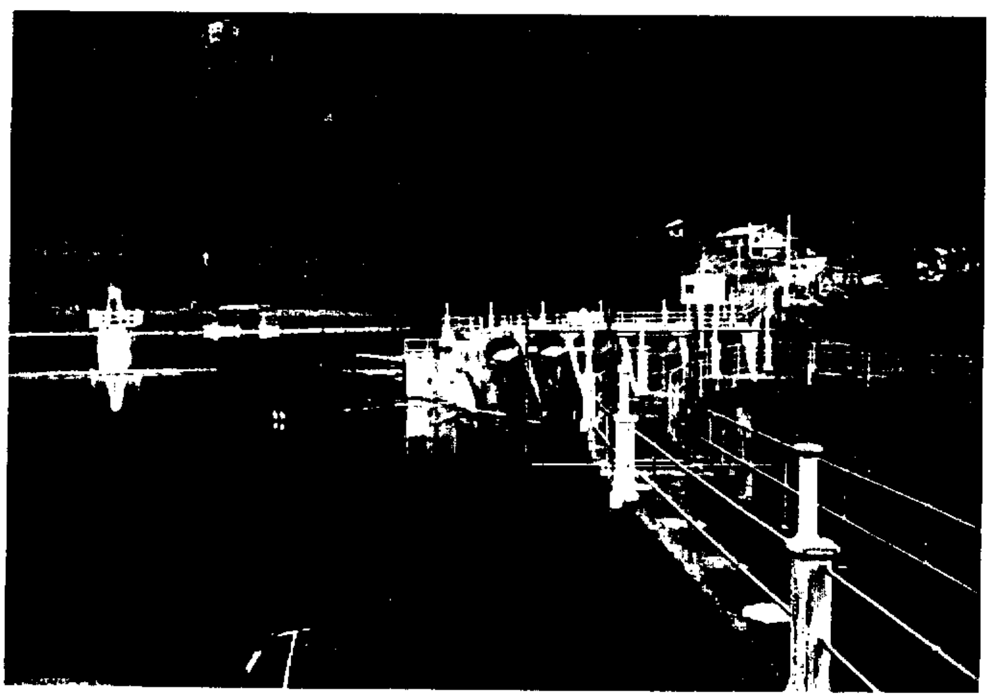
Elwha Dam - Closeup of Rock Formations at Bottom of Left Spillway

Elwha Dam - Closeup of Right Spillway During Spill.

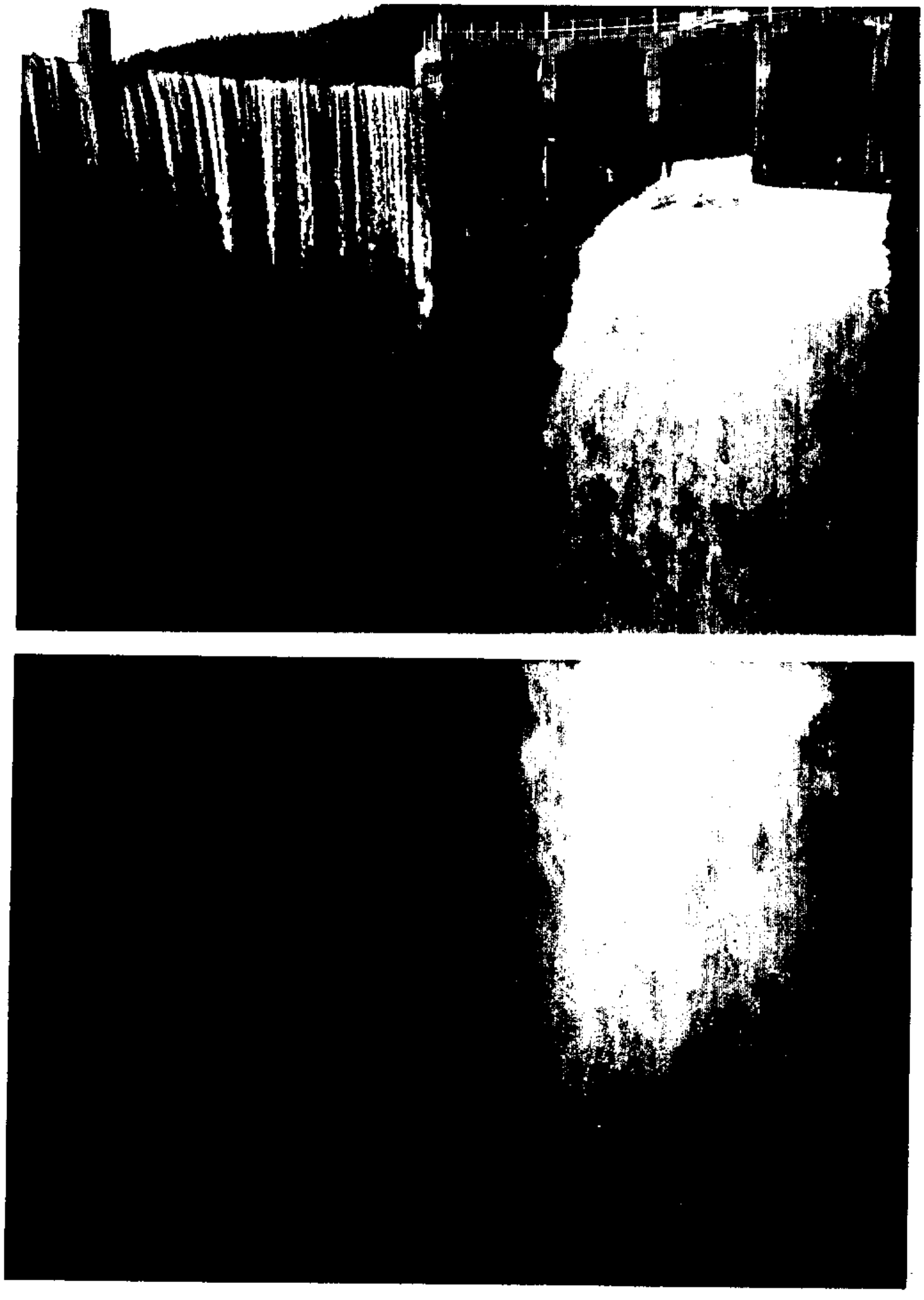
Elwha Dam - Right Spillway at Powerhouse. No Spill.
Flow is from leakage through gates and around the abutment.
Velocity barrier dam will be constructed in this vicinity.

Elwha Dam - Leakage around Right Abutment. Water will be utilized as part of fish ladder flow.

Aerial View of Glines Canyon Dam



Glines Canyon Dam - Forebay



Glines Canyon Dam - Spillway Section During Spill

Glines Canyon Dam - Free Overflow Section. Plunge pool depth is indicated by lower moss line near regulating outlet port.

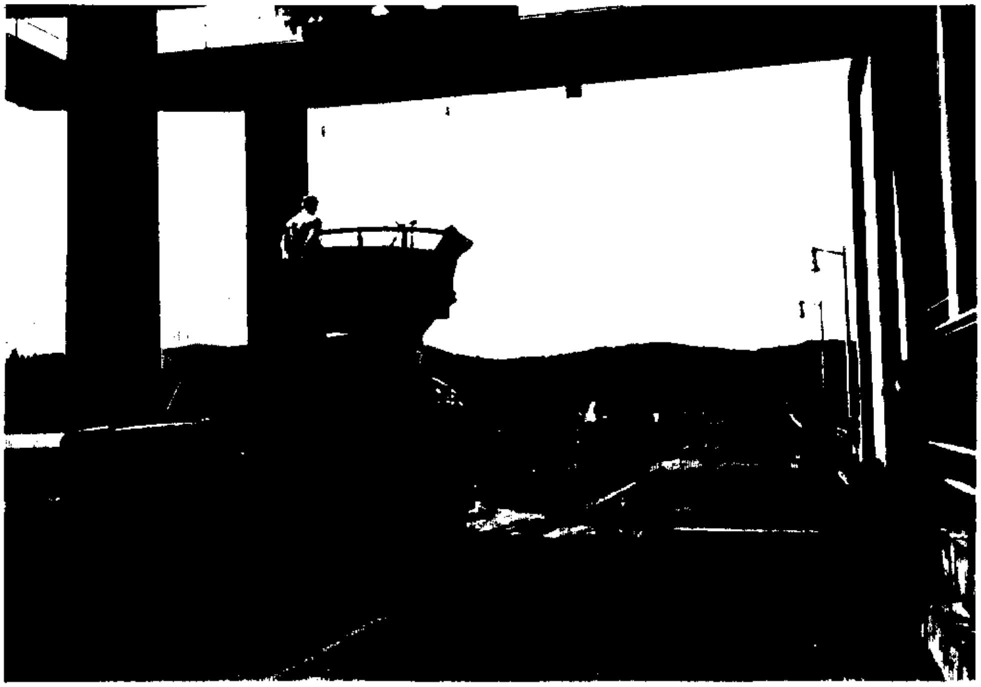
Glines Canyon Dam - Plunge pool dewatered. Water is from gate leakage.

Natural rock dam just downstream from plunge pool.
Results in 30-40' water depth in pool during spill.

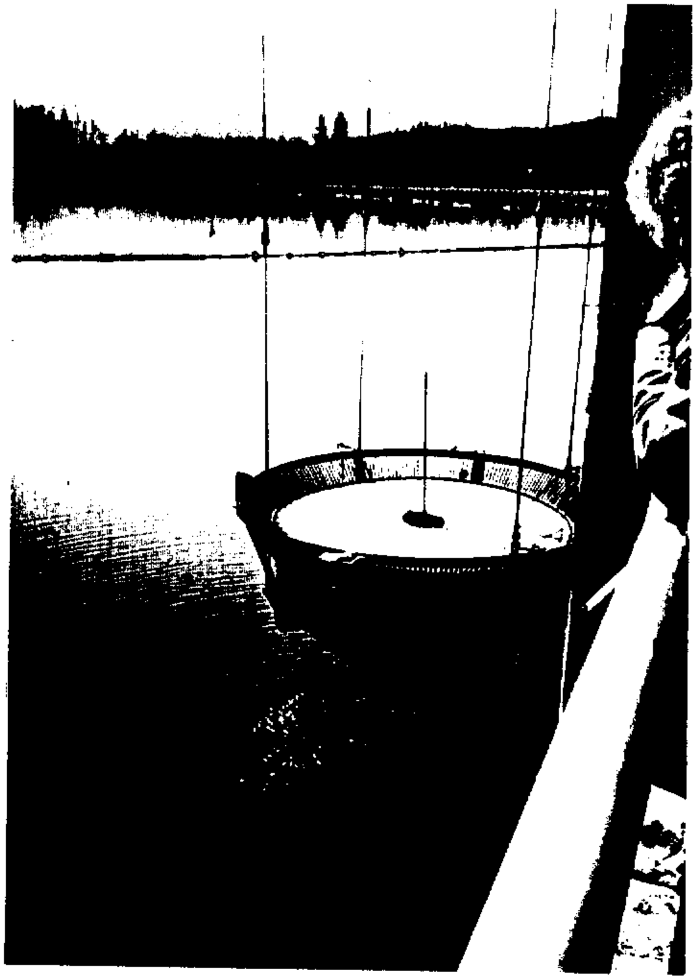
Fish trap used during 1983 fish mortality studies.

Fish ladder at Foster Dam, Santiam R., Oregon. Pool and weir type similar to the one proposed for the Elwha R. dams.

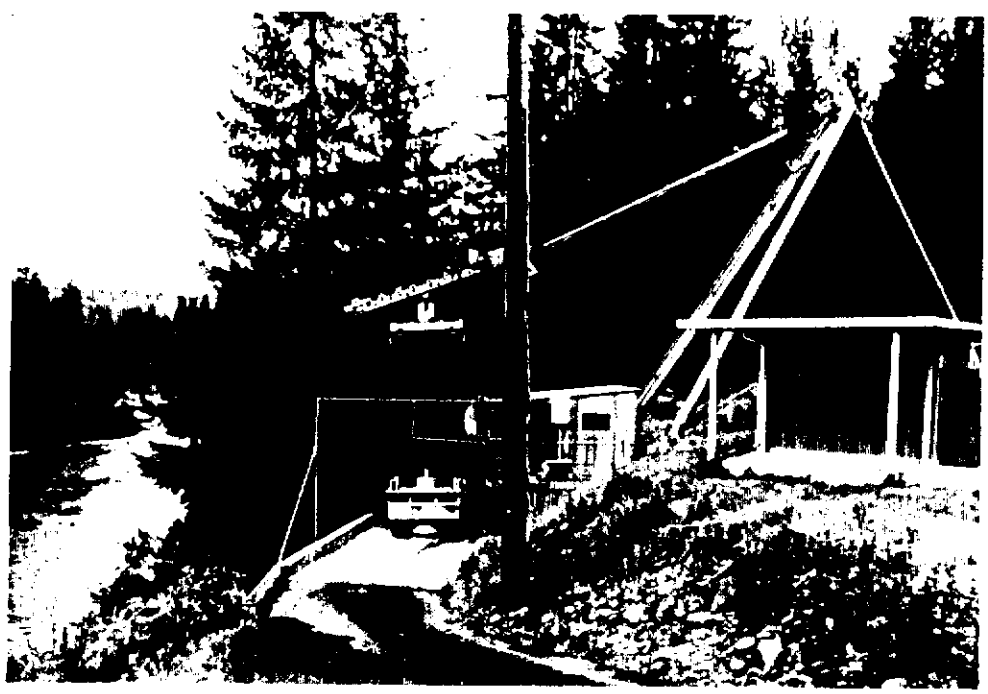
Foster Dam - Sorting chamber. Representative of one proposed for Elwha R. dams.



Foster Dam - Fish hopper unloading to tank truck.



Foster Dam - Fish hopper unloading directly to forebay.



Rivermill Dam, Clackamas R. Oregon, hopper and cable assembly similar to one proposed for Elwah R. dams.